Table 14. Continued.

| | Distribution by Region + Mammals |
|---|---|
| Mountain Beaver *Aplodontia rufa* * | K,CV,Mo |
| Ringtail *Bassariscus astutus* | NC,CV,Mo,CC,ES,SC,D |
| Beaver *Castor canadensis* | NC,CV,Mo,CC,ES,SC,D |
| Virginia Opposum *Didelphis virginiana* I | NC,CV,Mo,CC,SC |
| Mountain Lion *Felis concolor* * | NC,CV,Mo,CC,ES,SC,D |
| Bobcat *Felis rufus* | NC,CV,Mo,CC,ES,SC,D |
| River Otter *Lutra canadensis* | NC,CV,Mo |
| Striped Skunk *Mephistis mephistis* | NC,CV,Mo,CC,ES,SC,D |
| Yuma Myotis *Myotis yumanensis* | NC,CV,Mo,CC,ES,SC,D |
| Mink *Mustela vison* | NC,CV,Mo,ES |
| Dusky-footed Woodrat *Neotoma fuscipes* * | NC,CV,Mo,CC,SC |
| California Mule Deer *Odocoileus hemionus californicus* | NC,CV,Mo,ES,D |
| Black-tailed Deer *Odocoileus hemionus columbianus* | NC,CV,Mo,CC,SC |
| Muskrat *Ondratra zibethicus* | NC,CV,Mo,CC,ES,D |
| Harbor Seal (in tidal reaches) *Phoca vitulina* | NC |
| Raccoon *Procyon lotor* | NC,CV,Mo,CC,ES,SC,D |
| Western Gray Squirrel *Sciurus griseus* | NC,CV,Mo,CC,SC |
| Ornate Shrew *Sorex ornatus* * | CV,CC,SC |
| Pacific Shrew *Sorex pacificus* | NC |
| Water Shrew *Sorex palustris* | NC,CV,Mo,ES |
| Vagrant Shrew *Sorex vagrans* | NC,CV,Mo |
| Western Spotted Skunk *Spilogale gracilis* | NC,CV,Mo,CC,ES,SC,D |
| Brush Rabbit *Sylvilagus bachmani* * | NC,CV,CC,SC |
| Gray Fox *Urocyon cinereoargenteus* | NC,CV,Mo,CC,ES,SC,D |
| Black Bear *Ursus americanus* | NC,CV,Mo |
| Western Jumping Mouse *Zapus princeps* | CV |
| Pacific Jumping Mouse *Zapus trinotatus* | NC |

+ Regions (see Map of Regions, Figure __)
NC = North Coast/Klamath
CV = Central Valley
Mo = Modoc/Cascade
CC = Central Coast
ES = Eastside/Great Basin
SC = South Coast
D = Desert (Mainly represents Colorado River)

* Certain subspecies found along California rivers are rare

Sources: Brode and Bury (1984), DFG (1992a), Laudenslayer et al.(1991), Miller et al. (1989), Remsen (1978), Stebbins (1966), Williams (1986), Williams and Kilburn (1984), Williams et al (1989), Zeiner et al (1988, 1990a, 1990b); CNDDB Special Animals List, December 1992; CNDDB list of Habitat Associations, 1/31/92.

Figure 71. Rivers as Systems (Eel River).

# California Rivers: Their Nature, Function and Restoration

# 4

*A river seems a magic thing. A magic, moving, living part of the very earth itself—for it is from the soil, both from its depth and from its surface, that a river has its beginning.*
Laura Gilpin, *The Rio Grande.*

## Introduction

A river is more than a large stream of flowing water. Rivers collect and concentrate water and materials yielded by the land they drain. Rivers transport water, materials, organisms and people and their goods. Rivers bring water to otherwise dry environments. A river is a major influence on the landscape through which it flows, carving and sculpting the land and connecting land and water. At the same time a river is at the mercy of the land, passively receiving whatever runs into it—water, soil, rocks, nutrients, debris and pollutants.

Thus, a river is more than a channel of water. To manage rivers and to sustain them it is necessary to understand their functions as ecosystems. Ecosystems are systems incorporating the physical/chemical environment, biological organisms and processes, and the close interactions between and among them. In river ecosystems, the most important physical and chemical components are: 1) geomorphology, the landscape and land-forming processes; 2) hydrology, the flow and occurrence of water over time and space; and 3) water quality, the chemical and related properties of water as a liquid.

River ecosystems include both aquatic and riparian living resources, or biota. The aquatic biota are found submerged in the water, while the riparian biota are the more terrestrial, yet water-influenced, natural communities found on the banks and flood plains of a river. Important living resources of California river systems include the fishes of the aquatic environment and the woody plants (trees and shrubs) and associated wildlife of the riparian environment.

Within a river ecosystem the riparian vegetation, the aquatic biota and the environment are closely interrelated. For example, cottonwood trees growing on river banks produce an abundant biomass of woody branches, trunks and roots. This plant growth casts shade over the water to cool it and supports insects which fall into the water and are eaten by the fish. Tree roots or fallen trees, exposed by water erosion, provide hiding places for fish in their aquatic world.

This chapter describes the ecology of California's larger stream resources—those named and mapped as rivers by modern geographers—with an emphasis on those rivers considered navigable. There is no definition of how large a stream must be to be called a "river"; a look at the variation within California shows this is a very relative term. We use the term "rivers" to describe the most economically or socially important streams of an area, and to describe the relatively larger streams which are more controlling over the landscape and biota.

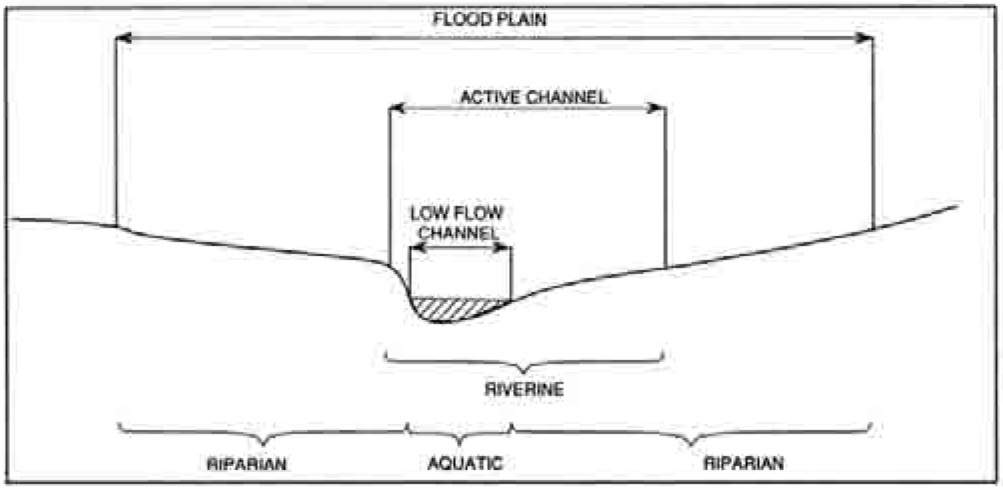
A river ecosystem must be recognized as continuous from its source to its ultimate destination, whether ocean, lake or underground basin. To focus on the public trust resources of rivers, we recognize the upstream connection, but concentrate on their downstream reaches, rather than headwater regions.

## Geomorphology and Hydrology

The dynamic nature of river channel features, commonly lost to the casual observer, is of enormous importance in understanding the effects of human activities on river channel stability. A river is composed of three closely linked elements: the drainage basin or watershed, the channel and flood plain, and the water (Keller, 1977). Rivers can be examined by their physical components as integrated channel-flood plain systems; or by their biological components as riverine-riparian ecosystems (Jensen and Platts, 1989). Physically, in rivers subject to annual flow variation, the active channel includes the permanently submerged bed, often called the low flow channel, and a near zone of seasonally exposed substrate (sand and gravel bars) which is frequently modified by floods. Ecologically, the "active channel" is also the riverine zone, and contains aquatic habitats (Cowardin et al., 1979; National Research Council, 1992). The flood plain encompasses the entire landscape subject to river geomorphic and hydrologic processes. However, this word is frequently used in reference to the less-often flooded, more terrestrial zone above the active channel, such as a flat valley adjacent to the channel. The flood plain is essentially synonymous with the biological riparian zone (Figure 72).

This section describes the processes of geomorphology and hydrology which link watersheds and water into integrated channel and flood plain river systems.

Figure 72. Channel Cross-section and Ecological Zones.




## *River Basins*

The runoff of water from higher elevations toward sea level produces the complexity of natural drainage networks, the variety of stream channel forms, and in part, the form of the landscape. This runoff is due to a fundamental imbalance in precipitation between land and sea. More water evaporates from the ocean surface than falls on it as precipitation, while more water falls on the continents than evaporates from their surface. Of the precipitation that falls on land, most is lost to evaporation or transpiration by plants. The remainder (typically less than half) runs off, draining via networks of stream channels to larger rivers and thence to inland lakes, sinks or oceans. The land area drained by a given river is termed its drainage basin or watershed, and is separated from adjacent watersheds by topographic high points termed drainage divides (Figure 73). Drainage basins can be defined on many scales, from large rivers such as the Sacramento River at Sacramento with a drainage basin of 23,500 square miles, to its tributary Cottonwood Creek, with a drainage basin of 922 square miles (Figure 74).

The basin is actually drained by the drainage network (Gregory et al., 1991), the system of branching waterways which combine into larger and larger streams, eventually forming rivers. Individual segments or reaches of the same river system can be very different because of local bedrock, topography, other geomorphic features and climate. Many rivers display characteristic changes along a gradient from headwaters to mouth.

Confined reaches occur mainly in mountainous, steep-gradient areas and have relatively straight, well-defined channels with narrow flood plains. Unconfined reaches are typical of low-gradient reaches in downstream parts of the basin; they typically have broad valley floors with wide flood plain and riparian zones (Gregory et al., 1991).

Figure 73. A River Watershed.

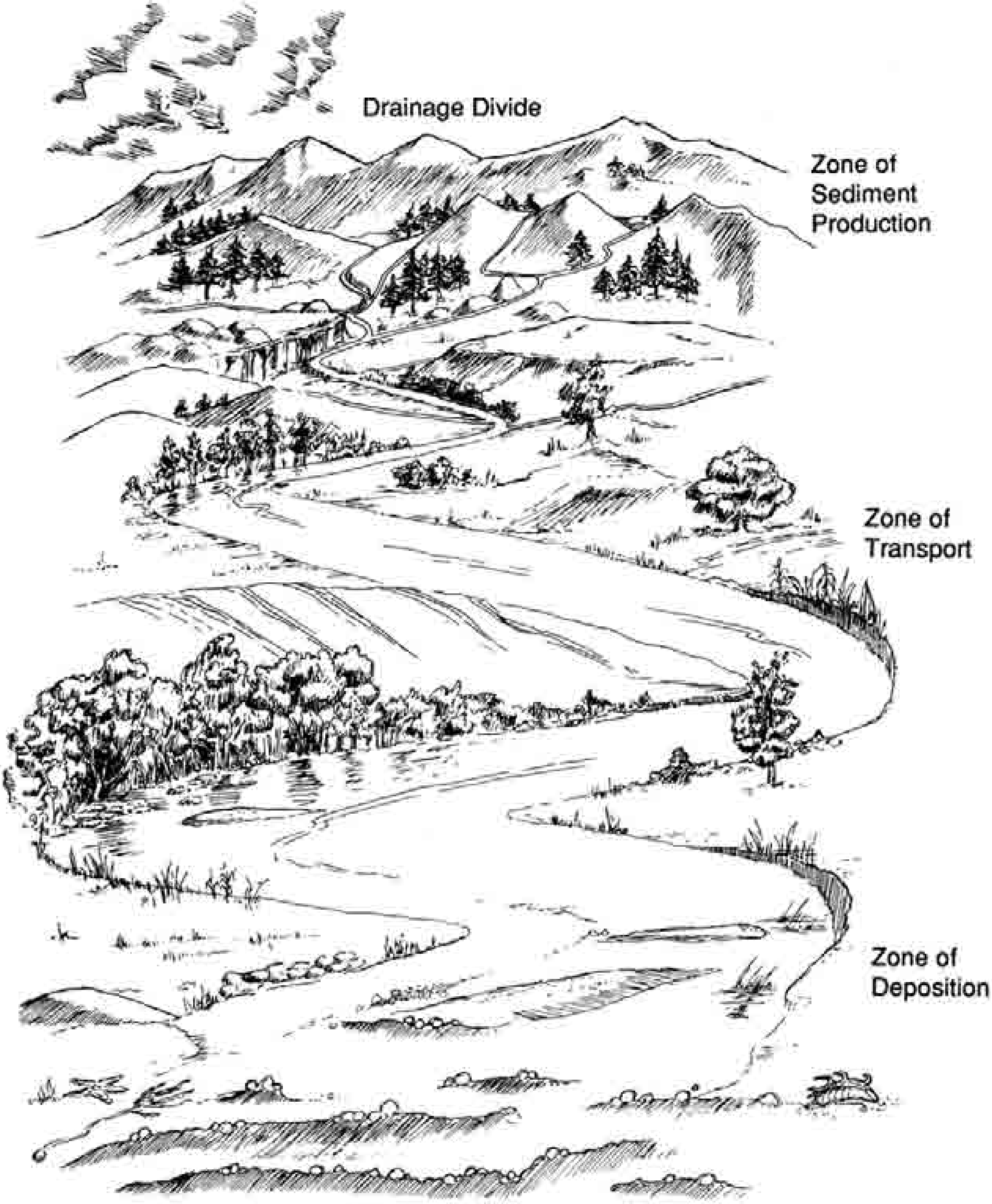
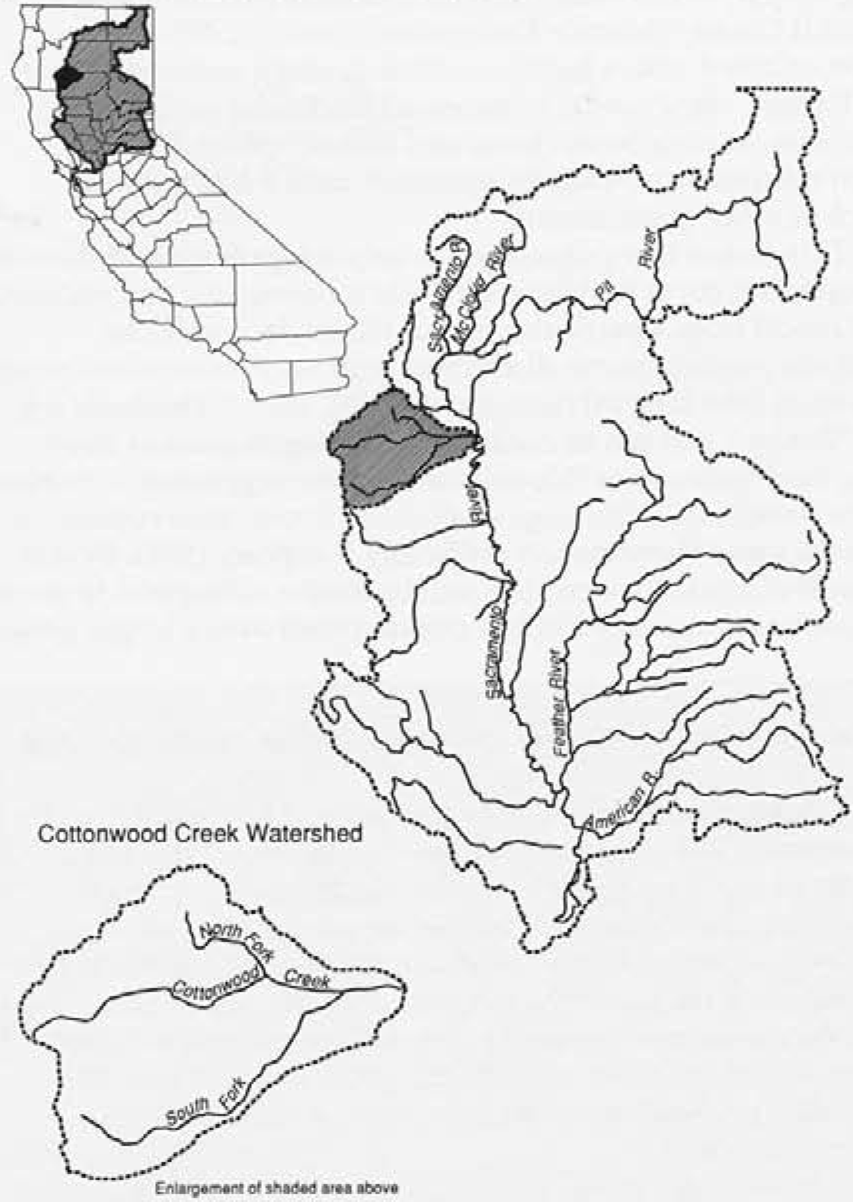


Figure 74. Sacramento River Watershed.




Watersheds are viewed as the fundamental landscape units because processes occurring upstream can affect downstream reaches, and to a lesser extent vice-versa. For example, clear-cutting of forests and construction of roads in the upper drainage basin can increase rates of erosion and sediment delivery to stream channels, overwhelming downstream channels with sediment and causing the channel to aggrade (build up its bed with sediment). This has occurred in the North Coast region, notably in Redwood Creek in Redwood National Park, where timber harvest in the upper watershed caused the downstream channel to aggrade, threatening the integrity of the tall trees grove (Kelsey et al., 1981).

If the level of the sea or a lake drops, tributary channels may incise (erode their beds downward to adjust their profiles). Tectonic uplift in the Coast Ranges has caused many streams to readjust by cutting deeper, as has occurred on the Mattole River watershed in Humboldt County (Mattole Restoration Council, 1989). Active incision, coupled with a highly erodible geology common to the Coast Ranges, often results in increased landslides as slopes are eroded away at their bases (Jones and Stokes, 1981b). Channel incision commonly propagates upstream until it hits resistant bedrock or other grade control.

Differences in topography, underlying geology, and the soil and vegetation cover within watersheds influence the amount and rate of runoff from a particular part of the landscape. Some watersheds produce storm discharges with very pronounced peaks over a short time interval (Beaumont, 1975). Such watersheds are called "flashy," and can be naturally occurring in areas of steep terrain, hard bedrock, or thin soils and sparse vegetation. Urbanization of a watershed, with large amounts of impervious surface, can induce the same phenomenon artificially (Leopold, 1991). By contrast, well-vegetated watersheds will be slower to respond to storms and have less pronounced runoff peaks spread over a longer period.

**John Wesley Powell and the Watershed as Landscape Unit**

Drainage basin boundaries and political boundaries, while frequently coincident in part, usually differ. Actions in the upper basin may result in substantial physical impacts to lower reaches of the river but because these areas are typically in separate counties, states or countries, coherent management of the entire river system does not occur. These problems were anticipated by an early director of the United States Geological Survey (USGS), a remarkable man whose sensible proposals to avoid jurisdictional conflicts were largely ignored.

John Wesley Powell, the first person of European ancestry to navigate the Colorado River through the Grand Canyon, epitomized the public servant of the Jeffersonian school. Powell is responsible for innumerable insights into the science of geology and hydrology, but his most important accomplishments were establishing the highly respected USGS; conceiving and promoting the topographic mapping program we now take for granted; standardizing symbols used on topographic and geologic maps; and founding the field of Native American ethnology.

Powell recognized the critical importance of water in western North America, and argued forcefully that water resources be managed by watershed, with political bound-

Continued on next page

aries drawn along drainage divides, so that watersheds would be managed by the same public agencies that managed water use downstream. Such coherent management would encourage land use policies designed to protect water supplies and encourage distribution of water (essential for agriculture in the semi-arid west) in an equitable and efficient fashion. Powell's public-spirited ideas conflicted with the frontier, extraction oriented politics of the time. After achieving many of his objectives, his reform proposals ran afoul of conservative politicians and he was driven from directorship of the USGS in 1894, after which he devoted most of his efforts to his ethnologic studies.

Source: Stegner, 1953.

## *Energy Dissipation and Sediment Transport*

As water flows from the upper reaches of the watershed downward through the drainage network, some of the potential energy of its elevation is converted into energy of motion. The remaining energy is expended on transporting sediment and is dissipated in turbulence from rough, irregular beds and banks, and through energy losses at bends.

### Energy of Motion

The steeper the channel, the more rapid the rate of energy dissipation (conversion of energy from potential to other forms). Steep streams typically have large rocks on the bed (with greater flow resistance and stability) with most energy losses concentrated in localized drops. These drops may be bedrock or boulder steps, step-pool reaches, or gravel-cobble riffles in pool/riffle reaches.

California's rivers possess energy in excess of that required to move water to sea level. Many Sierra Nevada rivers are high in the potential for hydroelectric power generation because of their steep reaches. Many hydroelectric power projects are run-of-the-river: They involve no large storage reservoirs, but simply divert flows from the channel into smooth canals or tunnels that convey the water at a gentle grade along the mountainside above the river. The river falls more steeply than the canal until the canal is 100-200 feet above river level, at which point the water is dropped abruptly through reinforced pipes (penstocks) driving turbines in the power plant.

## Sediment Transport

Much of a river's excess energy is used to move sediment, the soil and rock fragments eroded from the watershed. Sediment is transported in three ways. Dissolved load consists of weathering products in solution, suspended load consists of clays, silts, and sometimes sand that are held in suspension by turbulence in the water column, and bedload consists of larger, heavier grains of sand and gravel, sometimes up to boulder size, that move along the bed by rolling, sliding and bouncing.

The size of movable sediment grains depends on the water velocity (which depends upon water depth and channel gradient) of the flow and turbulence. The total amount of sediment moved in a river also increases with flow velocity. Since flow velocity increases with increasing flow, both the particle size and total amount of sediment movable by a river increases with flow. The rate of sediment transport typically increases as a power function of flow, that is, a doubling of flow typically produces more than a doubling in sediment transport. Because the rate of sediment transport is so much greater in higher flows, most sediment transport occurs during floods.

Viewed over a long time period, runoff erodes the land surface and the river network carries the sediment away. The upper watershed can be viewed as a sediment "factory," and the river channel as a "conveyor belt," which transports the products downstream to the ultimate depositional sites below sea level (See Figure 73). Along the length of the river system, the size of sediment changes from coarse gravel-boulder in steep upper reaches to dissolved materials, sands and silts in low gradient reaches.

Along this "conveyor belt," sediment in the river channel may appear stable in the short term but probably moves frequently (Leopold et al., 1964). A gravel bar in the Eel River may look much the same from year to year, but the gravel particles in it may be largely replaced each year (or every two years, or less frequently), as sediment moved downstream from an upper reach replaces sediment carried away.

Figure 75. Carmel River: Historic Changes in River Channel.

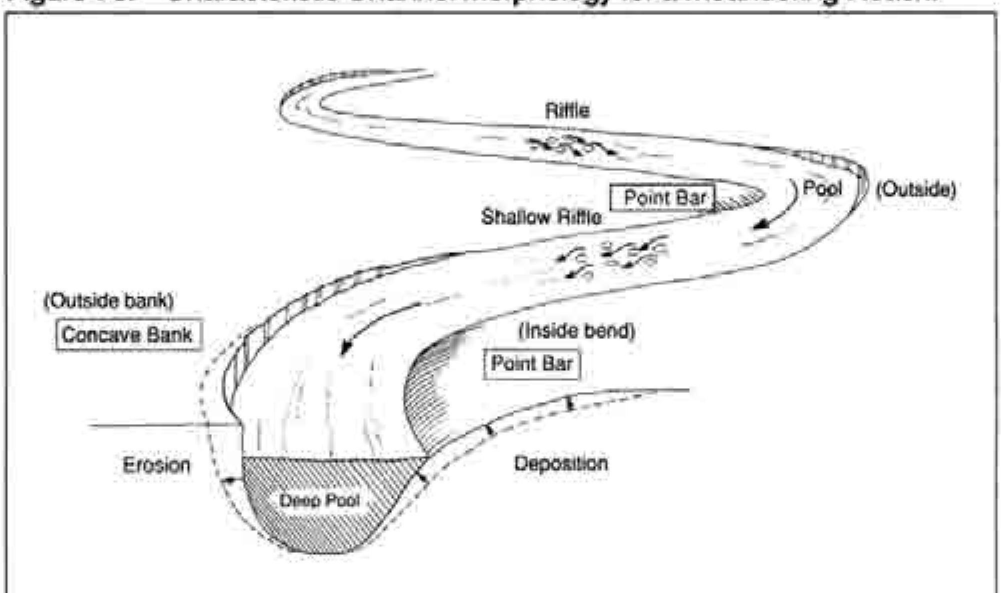

Source: G. Mathias Kondolf

While the sediments on the bed of the channel are mobile on a time scale of years, the sediments that make up a large river flood plain are mobile on a time scale of decades or centuries. The flood plain acts as a storage reservoir for sediments transported in the channel, alternately storing sediments (by deposition) and releasing sediment to the channel (by bank erosion). Figure 75 depicts migrations of the channel of the Carmel River since the first surveys in 1857. The river channel migrated over a quarter of a mile in places, with most channel shifts occurring during two large floods, in 1862 and 1911. The 1911 flood left behind a wide terrace of freshly deposited channel sediments. By 1960, the channel had cut 12 feet below this terrace surface, and the terrace had been subdivided for low density housing, despite the recent origin of the land.

## Dynamic Geomorphology

Natural rivers tend to develop complex beds with alternating deep and shallow areas, called pools and riffles, often with sand or gravel point bars deposited on the inside (convex) bank. Unconfined rivers typically have a sinuous form, illustrating the river's own formation and movement of bends as it meanders or migrates across its flood plain (Figure 76).

Figure 76. Characteristic Channel Morphology for a Meandering Reach.




Large lowland rivers, such as the Sacramento River below Red Bluff, often shape their channels and flood plains by large-scale meandering. Over centuries, the Sacramento River has moved laterally over its flood plain, creating a mosaic of land forms (Scott and Marquiss, 1984; Thompson, 1961). Rivers create meander loops by eroding to one side and depositing point bars on the other. As the river erodes, it enlarges the loop, building the older sections of the point bar higher as the river continues to move sideways. Eventually the river may cut off the loop in a short straight chute, and then begin eroding another bank to form a new loop. Old loops may become quite isolated from the river channel, creating oxbow lakes (Figure 77).

Another geomorphic phenomenon on many meandering rivers is the formation of natural levees, which are zones of higher ground adjacent to the channel. Natural levees form as floodwaters

Figure 77. River Meanders and Oxbow Lakes (Sacramento River).

just leave the channel, and the coarse sediments deposit first along the channel margins. The natural levees of the middle Sacramento River are up to 10-15 feet high and several miles wide in places (Scott and Marquiss, 1984; Thompson, 1961).

Thus, the flood plain is a dynamic feature closely related to the channel. In fact, the channel and the flood plain are best viewed as a single unit hydrologically and geomorphically, just as the watershed is a single landscape unit. Unfortunately, the natural functions of the flood plain have frequently been ignored, with disastrous effects.

### *Flood Frequency and Channel Form*

Flow in California rivers is exceedingly variable, except in unusual cases below large springs (such as the Fall River near Burney in northeastern Shasta County). This is due to the highly seasonal precipitation and intensity of the state's winter storms. Within the year, flows range from seasonal lows (in late summer in the Coast Ranges; in winter in higher elevation Sierra Nevada streams; non-existent in desert) to high flows (during winter storms along the coast; during spring snowmelt at higher elevations; shortly after a large rainstorm in desert). Flows also vary from year to year, depending on the abundance and intensity of precipitation for the year. The typical pattern of high flows is of particular importance in shaping a stream channel. This is especially true for rivers flowing through sediments, less so for rivers flowing through bedrock canyons. The history of floods on a given river can be analyzed to determine the probability of a certain sized flood occurring in a year. The flood that occurs, on average, once in every two years is the "two-year flood" or "$Q_2$"; the flood that occurs once in every ten years is the "$Q_{10}$." The probability that these flood levels will be exceeded in any given year is 50 percent and 10 percent, respectively. It is a common misconception that if a river experiences a 100-year flood one year, the probability of a similar sized flood the following year will be less. In fact, the probability of another 100-year flood the next year remains unchanged at one percent.

It is apparent that rivers with larger flows possess larger channels to convey the larger quantities of water. But how much larger must the channels be? More to the point, is there a flow to which the channel adjusts its geometry? During summer low flows most rivers do not fill their banks, but flow at reduced level, exposing gravel bars and other such features. At extreme floods, the river flows out of its banks and spreads across its flood plain. In many streams, the point at which flow just begins to exceed the capacity of the banks occurs at about the $Q_{1.5}$ to $Q_2$, designated as bankfull flow (Leopold et al., 1964). This implies that many channels are adjusted to these frequent small, high flows rather than to larger, but less frequent floods.

Figure 78. Trinity River Flow Changes With Dam.

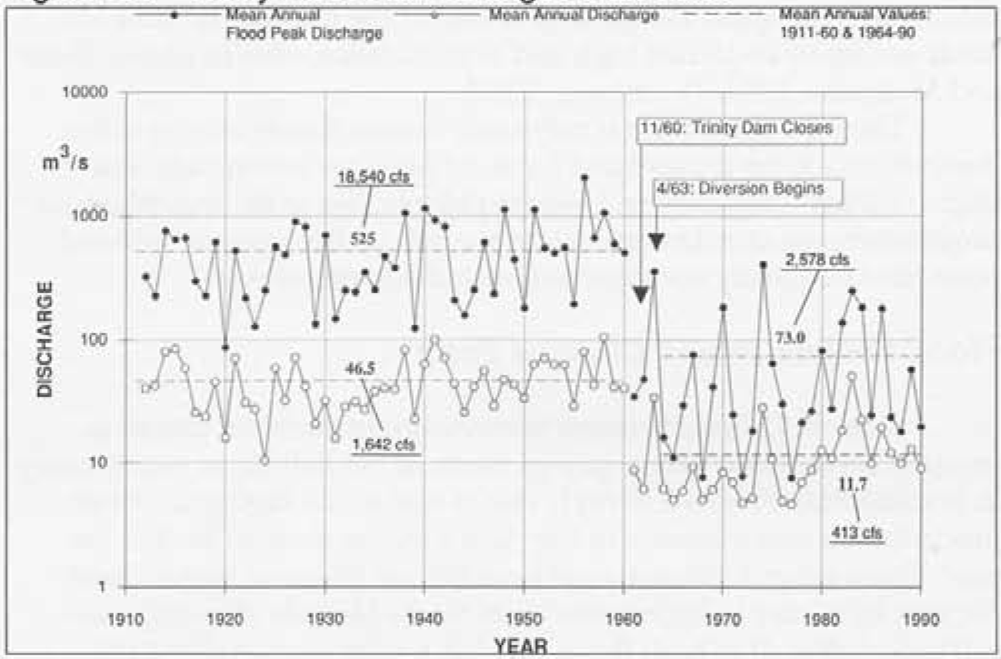



Figure 79. Trinity River Channel Before Dam.

Figure 80. Trinity River Channel After Dam.

Source for Figures 78, 79 and 80: G. Mathias Kondolf.

Given this apparent relation between flood frequency and channel form, it should be possible to estimate the bankfull flow of a river from measurement of its channel dimensions and slope alone. It also raises the question of how the channel may respond if bankfull flow is artificially increased or decreased. An example of a decreased bankfull flow is provided by the Trinity River after construction of Trinity Dam in 1960. Results of the flood frequency analysis show that prior to dam construction, the mean annual flood peak discharge was about 18,500 cfs and after dam construction only 1,600 cfs. The mean annual discharge was reduced from 2,500 cfs to 400 cfs (Figure 78). Given such a dramatic change in flood frequency, we might expect to see the dimensions of the channel decrease over the three decades since construction of the dam, and indeed, that has been the case (Figures 79 and 80).

## *Change Versus Stability*

River landforms are a result of the interaction of the watershed (its topography, bedrock, and soil-vegetation mantle) with the system's hydrologic regime (low and high flow amounts and occurrence). At any point in time, most streams in a natural condition seem to tend toward a dynamic equilibrium condition balancing the amounts of sediment entering and transported through the system to maintain what appears to be a stable channel and flood plain form. To put it simply: Erosion in one place or time is balanced by deposition in another place or time.

"Stability" of rivers is only relative, however, and must be considered in the context of temporal and spatial scales (National Research Council, 1992). In short reaches, over a few months or years, individual depositional bars may be scoured and redeposited frequently, but overall channel and flood plain appearance may not change significantly. Over long time periods, rare flood events coupled with meandering may cause large changes in landform, such as the large channel movements of reaches of the Sacramento River over the last century. Over large spatial scales, a single long reach of a meandering river will have a kind of constancy in the amounts and kinds of landforms—the number of bends, point bars and meander tracings—although individual locations will change. Over geologic time and over the entire regional landscape of a watershed, major environmental alterations such as those caused by tectonic movements and climatological changes can produce irreversible major changes in rivers.

The different geomorphic structures of a river system—its deep pools, shallow riffles, eroding banks, freshly deposited point bars and flood plain surfaces of various elevations—all create a diverse complex of river habitats for living organisms. Living resources respond not only to spatial variation, but to changes over time as well. As will be discussed in later sections, natural river systems support diverse and abundant biotic communities, including riparian gallery forests, hundreds of wildlife species and rich aquatic life, most of which not only can endure the dynamic nature of rivers but require it for best survival and development.

Figure 81. River Habitat Diversity.

## Water Quality

Truly aquatic biota, from fish down to the simplest bacteria and fungi, are closely dependent upon the physical and chemical nature of the water they inhabit. Aquatic organisms must derive gases and nutrients necessary for survival from the watery environment immediately surrounding them, and must similarly excrete waste products back into the same milieu. Because they cannot internally regulate temperatures and often cannot distinguish between substances necessary for survival and those which are toxic, or move toward or flee from them, they are particularly sensitive to environmental conditions posed by the water around them. River and stream organisms must additionally contend with life in moving waters.

What makes a river a river is its unidirectional flow of water. Flow in rivers and streams can be quantified in terms of discharge, which is the total volume of water moved over time, and current or velocity, the distance moved over time. Discharge is largely a function of watershed size and character and amount and distribution of precipitation. As noted, rain and snow patterns in California result in highly variable discharges between seasons and years. Velocity is a function of discharge and the channel's physical configuration. For a given discharge, velocity will be faster if forced through a smaller cross-sectional area than it will in a larger bed.

## *Geomorphology Dynamics*

Most river and stream flow in nature is not smooth and straight but is subject to varying degrees of turbulence (Reid and Wood, 1976). Water flowing over irregular beds and around curves of natural rivers shows uneven velocity distributions and develops many eddies and circular currents. Some generalities are possible: for curved reaches, currents are fastest at outside bends; for straight reaches, the fastest current is often in the middle; in areas of flow obstructions and steep gradient changes such as at sharp bends, over riffles, or near boulders and logs, turbulent mixing occurs. Patterns of currents within channels are usually quite different at low flow than at flood stage.

## *Turbidity*

The velocity and amount of turbulence determine the amounts of sediments put into and retained in suspension. Turbidity is the relative opaqueness of water, dependent primarily on the amount of suspended particulate matter present. Turbidity increases with higher discharge as the suspended load increases, due to the higher velocities and turbulence in the channel as well as usually increased sediment inputs from upland and bank erosion (Beaumont, 1975).

Sunlight is necessary for plant photosynthesis, the source of much primary productivity in rivers. The clarity of water and hence its ability to transmit sunlight to lower depths is an important determinant of the amounts and kinds of plant life which can thrive underwater, including algae attached to submerged surfaces, floating phytoplankton and rooted higher plants.

Most small stream reaches at low flow are relatively clear (Hynes, 1970). Lowland reaches of rivers, as they become larger, receive cumulatively more inputs of solids from the land as well as nutrients, and thus support more one-celled plants. They are thus usually more turbid than upstream reaches (Reid and Wood, 1976).

Water color in California rivers, as opposed to clarity, is primarily dependent on suspended substances during high flows and the presence of plankton during low discharge. The greenish hue of most lowland rivers in California during the warmer months of the year is due to plankton growth and, rarely, the presence of dissolved organic substances such as humic acids which can turn river waters dark.

## *Temperature*

Sunlight is important in rivers, not only for photosynthetic production, but as the major determinant of water temperature (Reid and Wood, 1976). The amount of solar radiation received by the waters of a river varies with angle of exposure, amounts of shade cast by riparian vegetation or landforms, and water depth, flow and clarity. Light is quickly attenuated by water and even more so when dissolved or suspended substances are present. Water temperature is also quite dependent on outside air temperature. In rare cases, river temperature is a function of cold (or warm) springs which feed it, such as the constantly cool lower McCloud River in northern California.

Temperature is important because of its direct influences on rates of metabolic processes; all organisms have optimal temperature ranges for their reproduction, survival and growth. Many aquatic life-forms have different temperature tolerances at different life stages, and many can acclimate to a certain degree to new temperature ranges. Temperature is also important indirectly in its effects on other qualities of water such as solubility of gases.

There are usually quite dramatic temperature differences between seasons and, depending on stream size, over a day or diurnally. Upstream river segments and smaller streams show much wider seasonal and diurnal variations in temperature than do larger streams and rivers (Goldman and Horne, 1983). The higher amount of suspended solids in the water in downstream reaches tends to increase absorption of heat, and so increases temperature (Reid and Wood, 1976).

## *Dissolved Gases*

Natural scientists know water as the "universal solvent" because of its ability to dissolve and ionize substances. No pure water exists in nature. River waters contain large amounts of dissolved inorganic and organic substances, including dissolved gases and nutrients necessary for life.

The most important gases in river waters are oxygen ($O_2$) and carbon dioxide ($CO_2$). External oxygen is required for metabolic processes (primarily cellular respiration) by all organisms but a few types of anaerobic microbes. Carbon dioxide is a waste product from most metabolic reactions, but is required by plants for photosynthesis.

Oxygen enters river and stream water through diffusion from the atmosphere and as a chemical by-product of photosynthesis. The amount of oxygen which dissolves into rivers is influenced by temperature and the degree of mixing or turbulence (Reid and Wood, 1976). Oxygen has decreased solubility in water with increased temperature. Typically, upstream reaches with a higher gradient, more turbulent flow and cooler temperatures have higher oxygen content than lowland reaches. Downstream river segments are not only warmer but have fewer riffles and rapids to physically aerate the water.

Carbon dioxide has a major role to play in the buffering of acidity of natural waters. Normal precipitation is somewhat acidic but most unpolluted natural streams are neutral to alkaline. Complex chemical reactions—involving carbon dioxide, calcium and magnesium ions, and calcium carbonate and bicarbonate, all in various balances—determine the pH or relative acidity of water (Hynes, 1970). The calcium and magnesium constituents come originally from rocks and soils of the watershed. Carbon dioxide in running waters is rarely in short supply. It normally comes from diffusion from the air and from buffering reactions involving carbonates.

Carbon dioxide is the reverse of oxygen in life processes; photosynthesis uses it up and metabolic processes produce it. Where there are high amounts of organic matter to be decomposed by biological activity, oxygen can be decreased, at the same time as there are high levels of carbon dioxide. This condition is eventually harmful to higher organisms such as invertebrates and fish. Downstream river reaches tend to experience decreased oxygen and increased carbon dioxide, due partly to higher turbidity, which decreases photosynthetic oxygen production, and also due to higher accumulations of organic matter to be decomposed.

In flooded soils, the oxygen/carbon dioxide balance is also critical for root survival of riparian plants. Diffusion of oxygen into air-filled soil pores is 10,000 times faster than when pores are filled with water. Within hours after flooding, soil microorganisms can exhaust available oxygen and produce a buildup of carbon dioxide. If flood waters stagnate over a period of time, root death may occur. However, in turbulent flood waters oxygen can diffuse into soil water (Kozlowski et al., 1991).

## *Dissolved Inorganics*

Water also contains large amounts of dissolved solids. Inorganic substances come primarily from land sources, collected as runoff passes over and through rocks and soils. Major dissolved minerals in natural rivers which are important to aquatic life include magnesium, calcium, sulfur, iron, sodium, potassium and silica. Phosphorous is necessary only in small amounts, but in its usual forms in nature it is unavailable for plant uptake. Phosphorous is often limiting to plant growth in aquatic environments, as evidenced by algal blooms when runoff containing phosphate detergents or fertilizers pollutes a waterway.

Nitrogen is a major constituent of proteins, and is needed by all organisms in large amounts. Nitrogen is a major component of the atmosphere, but cannot be used by most organisms until captured into ionic forms, chiefly nitrates, by microbes. Much nitrogen is recycled over and over through feeding, decay and plant uptake, mediated by microorganisms. Nitrates can also enter streams from the land (Goldman and Horne, 1983). Available nitrogen may be added to rivers and streams by the presence of alder trees, which have nitrogen-fixing capabilities in their roots similar to members of the legume family (Gregory et al., 1991).

There are a number of other elements which are necessary in minor amounts for life, many of which are heavy metals. Some, such as copper and zinc, usually become toxic to organisms in higher concentrations in the environment (Haslam, 1990).

### *Dissolved Organics*

All rivers contain high amounts of dissolved and particulate organic matter (Hynes, 1970). Stream ecologists distinguish between Dissolved Organic Matter (DOM) and Particulate Organic Matter (POM) (Cummins, 1974). As will be discussed later, river food chains and webs are highly dependent upon the instream processing of organic matter. Much organic matter in streams, especially smaller ones, comes from adjacent terrestrial environments. Leaves and twigs of riparian vegetation are primary sources. Insects and microorganisms break down raw plant materials into smaller pieces, which are cycled through feeding and decomposition networks. Bacteria and fungi also play important roles in stream and river nutrient and energy cycles.

Very dilute dissolved organic substances in rivers are also important for the homing ability of salmonids to return to natal streams (Goldman and Horne, 1983).

The amount of total dissolved solids (TDS), both inorganic and organic, is often used as an indicator of water quality, especially its suitability for human consumption, irrigation or industrial use. Salinity refers to the concentration of those substances which are in ionic form, a subset of TDS. The electrical conductivity (EC) of water is a commonly measured index of salinity. Salinity is normally not high in California rivers except near the ocean, where rivers meet the sea in estuaries. However, agricultural runoff has increased the salt concentrations of certain rivers, notably the lower San Joaquin River, to levels which seriously impair water quality for human use and sensitive river biota.

## Living Resources: Organisms and Communities

### *Overview of Biological Concepts*

Within ecosystems, living organisms each have a particular function, which is a combination of what they do—niche—and where they live—habitat. The niche of an organism refers to its role in a variety of interactions and processes, such as its place in trophic or food-related relationships, or in other direct interactions such as competition or parasitism. An organism's habitat is the particular place which provides environments suitable for survival.

Organisms can also interact directly or indirectly through habitat relations; organisms can modify the habitat of others or even be habitat themselves (Jones and Stokes, 1981a). For example, riparian tree and shrub vegetation is important habitat for many birds, mammals and other fauna, so much so that frequently the term "riparian habitat" is used synonymously with "riparian vegetation."

The assemblage of organisms in a particular geographic location or type of place is often referred to as a community. The term community (or natural community) denotes a close and predictable relationship between the kinds and numbers of organisms and the environment of a place.

Ecosystems are defined in large part by the relative closeness of organism interrelationships. For example, in river ecosystems, trees on flood plain lands and fish underwater may be closely linked through trophic and habitat relationships. Cottonwood trees, perhaps California's most important riparian plants, live in a mostly terrestrial habitat, but one with a high water table and which is subject to occasional major flood events. Fish require a water covered habitat of suitable temperatures and quality, and a plentiful food supply. Many native fish species require underwater structures such as boulders or large woody debris for cover and feeding. Cottonwood trees support high insect populations which can fall into the water of adjacent channels and provide food for fish. Branches and roots which extend over or under water and even whole fallen trees provide cover and shade for fish.

Figure 82. Typical Riparian Habitat.

An important function of an individual or population within a river ecosystem is its place in the transfer of energy and matter in trophic relationships. The base of food chains or webs consist primarily of green plants which can capture the energy of sunlight in photosynthesis and use it to produce biomass. This primary production is carried out by riparian trees and shrubs, attached algae, and free-floating phytoplankton. Watershed vegetation further removed from riparian zones can also be important sources of primary production in smaller streams. Riparian and aquatic animals in turn consume the plant material and each other. Organisms which eat plant biomass are called primary consumers. Animals which consume other animals are called predators, and are also considered secondary or even tertiary consumers. A special type of consumer is the decomposers, organisms (primarily microbes) which break down dead plant and animal material, returning nutrients to the environment or to be used again by plants.

The following is an introduction to the different types of organisms found in California river systems. It is not exhaustive, but is intended to provide a background for understanding rivers as systems and an appreciation of river natural history and its diversity across the state.

Some types of organisms live their entire lives in terrestrial habitats of the riparian environment, some exist exclusively under water, and some require both aquatic and riparian habitat elements for survival and reproduction. These differences in habitats cut across most taxonomic groups, so this discussion avoids divisions made along the more traditional lines of aquatic biology (limnology) versus terrestrial ecology.

## Organisms

### *Microorganisms*

The smallest organisms of ecosystems—bacteria, fungi and protozoans—are frequently overlooked in ecosystem descriptions, but play some of the most critical roles in energy and matter processing and cycling. Microorganisms are also significant to humans as pathogens (Fjerdingstad, 1975).

Bacteria and fungi, especially in aquatic environments, are important decomposers of organic material (Goldman and Horne, 1983). Microbes break down large pieces of animal and plant tissue into fine or dissolved organic materials which can feed zooplankton, insects or other invertebrates. While bacteria can break down cellulose, only fungi can break down lignin, the skeletal material of leaves and wood (Goldman and Horne, 1983). Decomposition by bacteria and fungi is an important step, transforming the input of leaves and woody debris from riparian vegetation into energy and nutrients available for aquatic food chains and webs (Cummins, 1974). Decomposer bacteria and fungi together with plant and animal debris and the organisms which feed on this material form the detrital community on stream and river bottoms.

Bacteria as a class have diverse functions (Goldman and Horne, 1983). They are important in ecosystem cycles of nitrogen, sulfur and iron, and some bacteria produce methane gas in low-oxygen environments such as dense muds. Bacteria can also break down polluting substances such as pesticides (Fjerdingstad, 1975) and oil (Goldman and Horne, 1983).

The presence of certain masses of bacteria and fungi are often indicators of organic matter pollution. A particular community of microorganism growth has been called "sewage fungus," a growth of bacteria, fungus, protozoans and some algae which encrust underwater surfaces in rivers subject to organic matter pollution (Haslam, 1990). In addition, the presence of coliform bacteria, normally found only in animal digestive tracts, in water is a likely indicator of sewage pollution (Goldman and Horne, 1983).

## *Plants*

In river systems, the most important groups of green plants are aquatic algae and riparian trees and shrubs. Rivers as a rule do not support much growth of aquatic macrophytes (large plants) such as pondweeds (Goldman and Horne, 1983). One reason is that smaller rivers and headwater regions have currents too swift, especially in winter floods, for these type of plants to survive. In larger lowland rivers, the current disturbance of the substrate might be less, but the water is usually too deep and turbid to allow light penetration to the bottom.

### Algae

Rivers have two types of algae. Benthic algae are species which are attached to the bottom and other surfaces; and phytoplankton are species which are free-floating in the water column. Generally, in small rivers and upstream reaches attached algae is common but plankton is rare. In downstream large river reaches, the increased turbidity and depth limits the growth of attached algae, but the increased nutrient concentration allows for an abundant phytoplankton community.

Benthic algae along with the other organisms that feed upon it, including many herbivorous invertebrates, is called the periphyton community in rivers and streams. Diatoms, green algae and blue-green algae are the most common groups of attached algae in streams and rivers (Goldman and Horne, 1983). The distribution of attached algae is related to substrate type, water temperature, current, sunlight and nutrient availability (Hynes, 1970). Many of these environmental factors vary with season, causing seasonal changes in algal growth.

In upstream areas, periphyton growth often detaches and enters the water column food web, but there is no almost no true plankton. Downstream, a phytoplankton community can develop, dominated primarily by diatoms (Hynes, 1970). This community is quite unstable with regard to species composition and abundance. Like attached algae, temperature, light and nutrients are important community determinants. For example, in the Sacramento River, large nutrient influxes after spring floods coupled with warming temperatures result in phytoplankton blooms in April, May and June (Greenberg, 1964 cited by Hynes, 1970).

## Riparian Plants

Riparian zones owe a major part of their character to their vegetation, which in relatively arid climates such as California, is usually very different from nearby upland areas. Broad-leaved, winter-deciduous trees and shrubs dominate riparian vegetation, especially in unconfined, meandering river systems. Lush and green in the summer and bare in the winter, riparian corridors can easily be recognized from a distance. In California, the most ubiquitous species are cottonwoods, willows, alders, sycamore and valley oak, although there is considerable variation in species composition of the vegetation throughout the state. The most common or indicative riparian plant species in California are listed in Table 13, Chapter 3 and special species are listed in Table 17 at the end of this chapter.

Riparian tree and shrub species share a unique set of ecological characteristics, most of which explain why they are limited to or highly successful in river environments: They are broad-leaved and winter-deciduous; fast-growing and often short-lived; require high soil moisture due to high transpiration (water loss) rates; able to produce suckers, sprouts, and new root systems; and tolerate seasonal flooding.

The large surface area of broadleaf winter-deciduous leaves provides maximum light capture, enabling extremely fast growth rates and high biomass production. The broad-leaf deciduous growth habitat of riparian species generally provides the ability to grow very fast, especially when young. On the other hand, the fastest growers, the willow and cottonwoods, have relative short life spans.

Large, thin deciduous leaves are a liability for water loss due to transpiration, unless soil moisture is plentiful enough such as along a river or stream. Riparian plant species are sometimes called phreatophytes ("well plants"), plants which have roots tapping moisture from the soil water table. Such plants have the ability to grow roots rapidly down to the water table and can readily absorb and conduct water efficiently through the plant, thus compensating for the rapid transpiration losses through thin succulent leaves. Riparian species, notably willows and cottonwoods, are limited almost exclusively to riparian environments largely because of their high water demand.

The broadleaf deciduous forest types of California riparian areas are similar to the most common kind of forests in the eastern third of the United States, Europe and parts of Asia. In the arid West, such forests are mostly limited to riparian environments. Two other adaptive characteristics of riparian trees and shrubs relate to the environmental stresses caused by river flooding. Most riparian woody species have an ability to sprout and sucker after mechanical damage, partial burial or bending (Figure 83). Well established trees can usually grow a new platform of roots in response to burial by river deposited sediments, even several feet thick. Riparian species also show a high degree of tolerance to the low-oxygen root environment in saturated soils. There are significant differences among species' ability to tolerate flooding, which causes them to segregate out over different flood plain and riverbed land elevations.

Figure 83. Willow Sprouting After Physical Damage.

Because river systems have frequent major disturbances such as flooding, erosion and deposition, and because many dominant riparian plant species have short life spans, the ability of riparian species to replace themselves by seed reproduction is important in maintaining the mosaic of riparian shrublands, forests and woodlands found in a natural flood plain. Many common riparian species produce abundant seed crops every year, ensuring dispersal whenever suitable habitat becomes available.

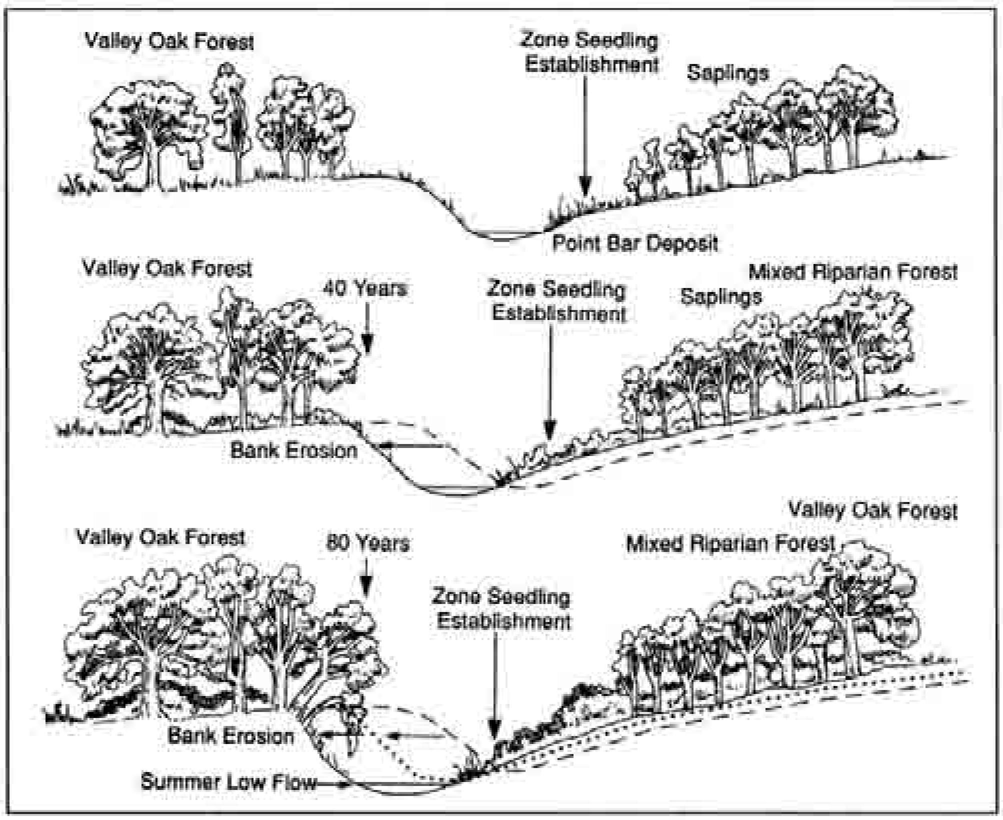
In the late spring, willows and cottonwoods disperse abundant small seeds. The "cotton" flying in the air in spring along many rivers and streams is their light seeds with fine hairs enabling wind dispersal. The small seeds can travel far, but have little stored energy for young plants. For these species to have successful seedling reproduction, they require sites of high sunlight and wet soils. Such conditions are met on substrates recently deposited and exposed from river physical processes such as new sand and gravel deposits still wet from receding flood waters. However, as water levels continue to drop over the summer, seedlings must be able to grow roots rapidly to maintain connection with moisture (McBride and Strahan 1984; Pelzman, 1973).

Riparian vegetation at any point in time and space is a result of the interactions between geomorphic and hydrologic processes, the environments they create, and the plants' responses. Riparian vegetation is comprised of species which can tolerate, and to some degree require, the high water and physical buffeting of the river environment.

In meandering river systems, flood plain riparian vegetation includes many different types such as gravelbar willow scrub, mid-terrace mixed forest and high terrace mature forest. These different communities occur in slightly different environments, depending on substrate type (e.g., sand vs. gravel), height relative to water elevations, distance from river, etc. Many of these communities are related to each other successionally, which means one community evolves into another over time, and so on, in a predictable sequence.

Plant succession is the change in composition of the dominant species over time. Studies on the Sacramento River illustrate the relationship between vegetation, plant successional processes and river geomorphic and hydrological processes (Conard et al., 1977; Strahan, 1984) (Figure 84).

Figure 84. Riparian Vegetation Succession along the Sacramento River.




As the river meanders, high banks are eroded on one side and low point bars are developed on the other. Willows and cottonwoods pioneer onto these newly deposited substrates, with seed dispersal and germination in spring timed to coincide with snowmelt flows receding in May and June. New seedlings grow very fast, developing into a willow-cottonwood thicket. Depending on the subsequent year's floods, the river channel may continue to erode high terrace land, but deposit on the other side. Established willow and cottonwoods may further deposition by impeding current flows over the low terraces. With the passage of time, the former point bar becomes higher and more stable, with new bars forming outward. Species not able to colonize at first are now able to seed on the developing terraces and become established under the shade of the willows and cottonwoods, which become tall trees. Eventually, terraces build up high enough so that species which are somewhat less tolerant of flooding but more tolerant of shade, such as valley oak, become established.

The later stages of riparian forest are often called climax or gallery forests. Typically, they are dominated by towering, aged cottonwoods and tree willows, or in the oldest stands, by spreading valley oaks, sycamore and black walnut. These forests have a well-developed understory of many other smaller tree species, shrubs and vines. The structural diversity of riparian gallery forests is unmatched in any other vegetation type in the state.

Cottonwoods and willows are not able to regenerate by seed in the mature forests of higher terraces, and when they die they are replaced by the more drought and shade tolerant species. Without river meandering, and its erosion and deposition, it is impossible for new large stands of cottonwood and willow to become established. Point bar deposition somewhere along the river, with receding flows in spring, are essential in order to replace older groves as they die naturally.

Fluvial processes also cause additional landform changes. For example, sudden river cutoffs create oxbow lakes, or meander scrolls, visible on aerial photographs. Overbank flooding can cause the deposition of natural levees, areas of high ground reachable only by the largest floods, in contrast to point bar deposition. Plant successional processes respond to all landforms and hydrologic environments created by the river. The result is a mosaic of plant communities over the flood plain, dependent upon a dynamic river system.

These patterns and relationships hold true for the Central Valley, most other large, meandering rivers of the Coast Ranges (e.g. the Russian and Salinas rivers) and, to a certain extent, the Colorado River. It should be noted there is considerable variation in riparian vegetation around the state, influenced in part by differences in regional flora and in part by differences in the physical/chemical environment. For example, in northwestern California, redwood and Sitka spruce (two evergreen conifers) are common components of riparian vegetation, and Colorado River riparian vegetation contains mesquite "bosques," or woodlands. In confined river systems, such as along parts of the Klamath, vegetation does not often develop into later mature stages; the constant fluvial actions keep vegetation in a state of "perpetual succession" (Campbell and Green, 1968).

## *Animals*

The fauna, or animal life, of rivers includes diverse forms representing all major taxonomic groups on earth. Of particular interest to resource managers is the traditional grouping of fish, reptiles, amphibians, birds and mammals which is usually meant by the term "fish and wildlife." However, invertebrates, including zooplankton, worms, molluscs, crustaceans and insects are equally important components of river ecosystems.

### Invertebrates

In abundance and diversity, insects are among the most successful and dominant animal forms on earth, and their significant role in river ecosystems is unquestionable. Insects important to river and stream ecosystems include some species which are purely terrestrial, some which are purely aquatic, and many which live a portion of their lives in both aquatic and terrestrial environments. The later two types are both commonly called "aquatic" insects. Aquatic insects are the most important group of primary consumers in stream and river food chains and webs linking plants to fish (Goldman and Horne, 1983). Many aquatic insects emerge from the water environment in their mature stage, living as adults in the riparian zone, where they are major components in the diets of riparian bird and bat species (see review by Jackson and Resh, 1989).

About 2,000 species in California are considered aquatic or semiaquatic, occupying water for at least part of life (DWR, 1982). Major groups are mayflies (*Ephemeroptera*), dragonflies (*Odonata*), stoneflies (*Plecoptera*), caddisflies (*Trichoptera*), dobsonflies and alderflies (*Megaloptera*) (Erman, 1984; Goldman and Horne, 1983). Members of the fly and mosquito order (*Diptera*), including midges, blackflies, craneflies and mosquitos, are also important insects of river systems as food for fish and riparian birds and as pests to humans and other animals (Faber et al., 1989; Goldman and Horne, 1983).

Aquatic insects, including the aquatic larval and nymph forms of flying species, have evolved remarkable and diverse adaptations for life in running water (Hynes, 1970). Many of these adaptations deal with the problem of staying in one place in a moving environment, including flattening and other streamlining of the body, claspers, suckers, hooks and sticky substances. Despite such adaptations, benthic (bottom dwelling) insects frequently become detached, floating downstream in the current.

Benthic insects which have released or otherwise detached, together with terrestrial insects which fall into the water and detached algae, form an important source of food for aquatic organisms called drift. Drift may be the predominant food source for fish in environments otherwise too deep and swift to have benthic community development (McGinnis, 1984).

In recognition of the importance of function, aquatic fauna, primarily insects, have been classified and described by their method of feeding, rather than by taxonomic grouping (Cummins, 1974).

Table 15. Feeding Methods of Aquatic Fauna.

| Functional Group | Food source |
|---|---|
| Predators | Motile food |
| Scrapers (grazers) | Attached algae |
| Collector-filterers | Drifting plant and animal fragments, wastes, microorganisms |
| Collector-gatherers | Sunken plant and animal fragments and wastes |
| Shredders | Large plant parts: leaves, bark, twigs, logs, seeds, cones, etc. |

Other aquatic invertebrates include molluscs (e.g. clams and snails), crustaceans (e.g. crayfish) and several groups of worms. The fauna of stony bottom and fast current environments of upstream reaches is typified by stoneflies, caddisflies, mayflies and dobsonflies, while worms tend to be more prevalent in softer sediments found in lowland rivers. Tubificid worms and midge larvae are tolerant of lower oxygen and higher nutrient environments characteristic of lowland river bottoms and thus can also be indicators of river pollution (Haslam, 1990; Hynes, 1970; Reid and Wood, 1976).

Terrestrial insects in the riparian zone have many of the same functions as aquatic forms. As noted above, they are food items for fish and are very important for riparian bird species, as well as other vertebrates and invertebrates. Some insects themselves are predators, feeding on other insects and invertebrates. Others are important herbivores that feed on succulent riparian plant growth, have a role in the breakdown and decomposition of dead plant and animal matter, and are major pollinators (Faber et al., 1989).

Three species of invertebrates associated with California rivers have been listed as threatened or endangered by the state or federal government: the Valley Elderberry Longhorn Beetle, California Freshwater Shrimp and the Shasta Crayfish. The small number of listed invertebrates does not mean that many more are not at risk, but probably indicates instead a lack of adequate information (Eng, 1984).

The riparian Valley Elderberry Longhorn Beetle, a federal Threatened Species, is found only in the Central Valley, and requires elderberry plants as host plants for both immature and mature stages (Eng, 1984). Two aquatic crustaceans, California Freshwater Shrimp and Shasta Crayfish are both state and federal Endangered Species.

The California Freshwater Shrimp is limited to lowland streams in Marin, Sonoma and Napa counties. The Shasta Crayfish is found in Shasta County in the Pit River system, including the Fall River Drainage (CDFG, 1992).

**Fishes**

The California native fish fauna is extremely varied—from the once abundant runs of salmon and steelhead swimming the waters from mountain streams to the Pacific Ocean, to tiny species of the most limited distribution and numbers in desert oases. About half of all native fish species and subspecies are found only in California (Moyle et al.,1989).

Fish are perhaps the most important indicator of aquatic biodiversity. Not only are fish the best studied of all aquatic organisms, they are excellent indicators of environmental conditions and have major influences over other aquatic life (Moyle and Leidy, 1992). Over two-thirds of the 116 native California fishes have already declined to the extent they are considered species of concern, including a number which are extinct entirely or extirpated from their native ranges within this state (Moyle and Williams, 1990).

The decline of native fish fauna is indicative both of habitat degradation and the introduction of nonnative fish species (Moyle, 1986). In California at least 48 nonnative species have become established (McGinnis, 1984). The Western United States have fish fauna comprised of 30 to 60 percent introduced species, compared to about 10 percent for the East (Moyle, 1986). Moyle suggests the high number of introduced species in the West is partly because native fish diversity in any one drainage was naturally low to begin with, and partly due to severe environmental degradation which created habitats more favorable for the nonnative species.

River and stream fishes are often divided into two major groups: resident and anadromous. Resident fish live their entire lives in freshwater, usually in a limited reach of river or stream. Anadromous fish spawn in freshwater, the young migrate to the sea to mature, then adults return again to freshwater.

The principal fishes of California rivers are shown in Table 16. More thorough lists and descriptions of individual species' ecology can be found in McGinnis (1984), Moyle (1976), and Moyle et al. (1989).

Fish assemblages are often described as either cold water communities or warm water communities (DWR, 1982). In general, cold water fish require aquatic habitats with temperatures below 68°F, high oxygen content, good water clarity, high turbulence and stony beds. Warm water fish can survive conditions of higher temperature, doing well at 80°F, lower oxygen, high turbidity and mud bottoms. River habitats actually are more variable than the two general types outlined above.

Table 16. Common Fishes of California Rivers.

| | Distribution by Region + |
|---|---|
| White Sturgeon *Acipenser transmontanus* A | NC,CV,CC |
| American shad *Alosa sapidissima* IA | NC,CV,CC |
| Sacramento sucker *Catostomus occidentalis occidentalis* | NC,CV,Mo,CC |
| Klamath smallscale sucker *Catostomus snyderi* | NC |
| Tahoe sucker *Catostomus tahoensis* | ES |
| Prickly sculpin *Cottus asper* | NC,CV,CC,SC |
| Paiute sculpin *Cottus beldingi* | ES |
| Riffle sculpin *Cottus gulosus* | NC,CV,C |
| Pit sculpin *Cottus pitensis* | Mo |
| Upper Klamath marbled sculpin *Cottus klamathensis klamathensis* | NC |
| Lower Klamath marbled sculpin *Cottus klamathensis polyporus* | NC |
| Coastrange sculpin *Cottus aleuticus* | NC,CC |
| Red shiner *Cyprinella lutrensis* I | D |
| Common carp *Cyprinus carpio* I | NC,CV,Mo,CC,ES,Sc,D |
| Threadfin shad *Dorosoma petenense* I | CV,SC,D |
| Western mosquitofish *Gambusia affinis* I | NC,CV,Mo,CC,ES,SC,D |
| Fully plated threespine stickleback *Gasterosteus aculeatus aculeatus* A | NC,CV,CC,SC |
| Partially plated threespine stickleback *Gasterosteus aculeatus microcephalus* | NC,CV,CC,SC |
| Lahontan creek tui chub *Gila bicolor obesa* | ES |
| Klamath River tui chub *Gila bicolor bicolor* | NC |
| Pit River tui chub *Gila bicolor* subsp. | Mo |
| Blue chub *Gila coerulea* | NC,Mo |
| Wakasagi *Hypomesus nipponensis* | NC,CV |
| Sacramento tule perch *Hysterocarpus traski traski* | CV,Mo |
| White catfish *Ictalurus catus* I | CV,CC,SC |
| Black bullhead *Ictalurus melas* I | CV,Mo,CC,ES,SC,D |
| Brown bullhead *Ictalurus nebulosus* I | NC,CV,Mo,CC,ES,SC,D |
| Channel catfish *Ictalurus punctatus* I | CV,Mo,ES,SC |
| Pit-Klamath brook lamprey *Lampetra lethophaga* | Mo |
| Pacific brook lamprey *Lampetra pacifica* | NC,CV,CC |
| Sea-run Pacific lamprey *Lampetra tridentata tridentata* A | NC,CV,CC,SC |
| Sacramento hitch *Lavinia exilicauda exilicauda* | CV |
| Monterey hitch *Lavinia exilicauda harengus* | CC |
| Sacramento roach *Lavinia symmetricus symmetricus* | CV |
| Green sunfish *Lepomis cyanellus* I | NC,CV,Mo,CC,ES,SC,D |
| Warmouth *Lepomis gulosus* I | CV,D |
| Bluegill *Lepomis macrochirus* I | NC,CV,Mo,CC,ES,SC,D |
| Redear sunfish *Lepomis microlophus* I | CV,Mo,CC,ES,SC,D |
| Inland silverside *Menidia beryllina* I | CV |
| Smallmouth bass *Micropterus dolomieui* I | CV,Mo,CC,ES,SC,D |
| Largemouth bass *Micropterus salmoides* I | NC,CV,Mo,CC,ES,SC,D |
| Striped bass *Morone saxatilis* IA | NC,CV,D |
| Golden shiner *Notemigonus crysoleucas* I | NC,CV,CC,SC,D |
| Fall run chinook salmon *Oncorhynchus tshawytscha* A | NC,CV |
| Late-fall run chinook salmon *Oncorhynchus tshawytscha* A | CV |
| Winter run chinook salmon *Oncorhynchus tshawytscha* A * | CV |

Continued on next page.

Table 16. Continued from page 209.

| | |
|---|---|
| Spring run chinook salmon *Oncorhynchus tshawytscha* A * | NC,CV |
| Coho salmon *Oncorhynchus kisutch* A * | NC,CC |
| Resident rainbow trout *Oncorhynchus mykiss gairdneri* | NC,CV,Mo,CC,ES,SC |
| Fall/Winter run steelhead *Oncorhynchus mykiss gairdneri* A | NC,CV,CC,SC |
| Spring/Summer run steelhead *Oncorhynchus mykiss gairdneri* A * | NC |
| Sacramento blackfish *Orthodon microlepidotus* | CV,CC |
| Yellow perch *Perca flavescens* I | NC |
| Bigscale logperch *Percina macrolepida* I | CV |
| Fathead minnow *Pimephales promelas* I | CV,D |
| White crappie *Pomoxis annularis* I | CV,Mo,SC,D |
| Black crappie *Pomoxis nigromaculatus* I | NC,CV,Mo,CC,SC,D |
| Mountain whitefish *Prosopium williamsoni* | ES |
| Sacramento squawfish *Ptychocheilus grandis* | NC,CV,Mo,CC |
| Flathead catfish *Pylodictus olivaris* I | D |
| Klamath speckled dace *Rhinichthys osculus klamathensis* | NC |
| Lahontan speckled dace *Rhinichthys osculus robustus* | ES |
| Sacramento speckled dace *Rhinichthys osculus* subsp. | CV,Mo |
| Lahontan redside *Richardsonius egregius* | ES |
| Brown trout *Salmo trutta* I | NC,CV,MO,ES,SC,D |
| Brook trout *Salvelinus fontinalis* I | NC,CV,MO,ES,SC,D |
| Eulachon *Thaleichthys pacificus* A | NC |

I = Introduced; A = Anadromous

**+ Regions** (see Map of Regions, Figure 69)
NC = North Coast/Klamath
CV = Central Valley
Mo = Modoc/Cascade
CC = Central Coast
ES = Eastside/Great Basin
SC = South Coast
D = Desert (Mainly represents Colorado River)

* Winter and spring run chinook, coho, and spring/summer steelhead are now rare

Sources: McGinnis (1984), Moyle (1976), Moyle and Yoshiyama (1992), Moyle et al. (1989), Robins et al. (1991).

There is variation at many levels—between different drainage systems, along longitudinal gradients, between pools and riffles within one reach, and between years and seasons in the same reach.

Trout are the archetypical cold water fish, not only in California, but in the rest of North America and Europe as well (Moyle, 1986). They are often joined by sculpins, speckled dace, and suckers. Warm water downstream river habitats commonly support "deep bodied" fish such as the Sacramento perch or tule perch. In their natural state, California lowland rivers were dominated by these native perches, and native minnows such as hitch, squawfish, Sacramento blackfish and Sacramento splittail (Moyle, 1976). Today, such habitats are dominated by introduced species from the sunfish and catfish families, and a few others. The native species have been eliminated or severely reduced in range and numbers.

A number of fish groups are distributed over many habitats. Suckers, roach and squawfish are widespread, and are especially common in environments transitional between cold and warm water habitats such as in the Sierran foothills or many coastal rivers (Moyle, 1976).

Anadromous fish must live in many different habitats, migrating upriver or downriver depending on the stage in their life cycle. Most anadromous species in California are important fishery resources, including members of the Salmon family, sturgeon and the introduced American shad and striped bass. The Pacific salmon, more than any other fish, is vitally important to human culture in western North America. Knowledge of their life history is critical to some of most significant issues of river management in California.

### *Pacific Salmon*

The Salmon family (Salmonidae) includes both anadromous and freshwater forms. The major native salmonids found in California rivers are all closely related, belonging to the same genus, *Oncorhynchus* (Smith and Stearly, 1989). They are the chinook (king) salmon, coho (silver) salmon, and several forms of steelhead/rainbow trout and cutthroat trout. Salmon, steelhead and sea-run coastal cutthroat are anadromous, while the rainbow trout and other types of cutthroat trout are resident species.

Anadromous salmonids have a remarkable life cycle. They begin life as eggs spawned in freshwater rivers and streams, then, as tiny young fish, rear in the streams where they were hatched. After a period of growth, sometimes months but up to a year or more in some species, the developing young fish migrate downstream to the sea. Their major growth occurs as they roam the ocean pasture for several years, covering thousands of miles. In one of the animal kingdom's most extraordinary feats of migration, adult salmon return to reproduce in the same rivers that spawned them, often to the exact same reach or tributary.

Salmonids separate into distinct populations among different locations, and may segregate populations in one place further by migrating at different times. Runs at different times within a single species or subspecies are called races. California chinook are generally fall or spring run, although the Sacramento River is unique in having four different races—the fall, late fall, winter and spring runs. The fall-run is the most numerous chinook race in the state today. Steelhead are considered to have two races, the more prevalent fall/winter run, and the spring/summer run. Separate races have not been identified for coastal cutthroat and coho salmon.

With such a high degree of reproductive isolation among different river systems and among different races, Pacific salmon species are considered to be made up of distinctive stocks (See review by Nehlsen et al., 1991). Stocks are identified by taxonomic grouping (species or subspecies), river or stream system, and migratory season. A stock of Pacific salmon judged to be an evolutionary significant unit (ESU) of a species is itself considered a "species" under the federal Endangered Species Act (National Marine Fisheries Service, 1991). An example of the stock concept is the listing of the Sacramento River Winter-run Chinook as a federal Threatened and state Endangered species.

Figure 85. California Steelhead Distribution, 1900s.


Historically, anadromous salmonids were found throughout the Central Valley drainages and in coastal streams and rivers the entire length of the state. The chinook is the largest Pacific salmon and its distribution in California is correlated with the state's biggest rivers. The largest runs of the chinook are in the Sacramento-San Joaquin systems of the Central Valley, with other major populations on the Klamath, Smith and Eel rivers of the North Coast (Fry, 1979). Coho typically spawn in smaller coastal streams and tributaries

Figure 86. California Steelhead Distribution, 1980s.

from Monterey Bay north (Moyle, 1976). Coastal cutthroat are fish of the Pacific Northwest rainforest belt extending south in California only down to Humboldt Bay (Trotter, 1989).

Steelhead once migrated up all significant streams of the state which had a connection to the ocean, including most southern California rivers. Of all the major California salmonids, steelhead have suffered the most dramatic decline in distribution. They currently occur mainly in northern California rivers and streams, having been all but eliminated from the Central Valley and South Coast (DFG, 1991c) (Figures 85 and 86).

### *Life History of the Salmon Family*

The ecological requirements of salmon, steelhead and sea-run cutthroat trout are similar. They must have free access to the ocean and back to the spawning grounds. To survive and reproduce at their maximum levels they need cool or cold water, with a reasonably stable flow regimen and good quality, including high oxygen content, especially in spawning areas. Optimal and tolerated water temperatures vary between different species of salmonids, different life stages within a species, and between locally acclimated populations. Most Pacific salmonids prefer temperatures somewhere between 40° and 60°F (Allen and Hassler, 1986; Barnhart, 1986; Bjornn and Reiser, 1991). If water temperatures change out of the preferred range, such as with normal seasonal variation, salmonids will often move to other areas, if available, to avoid suboptimal temperatures (Bjornn and Reiser, 1991).

Also essential for maintaining healthy salmonid populations is habitat with proper current velocity, water depth, a varied and abundant food supply, and adequate space for spawning and for growth of eggs, young and juveniles. Salmonids are closely dependent on the physical nature of the water course (spawning gravels, cover, pools, riffles, etc.).

The chinook salmon life cycle is a good example of the exacting requirements of these fish. (See Allen and Hassler, 1986; Moyle, 1976). Adult fall-run chinook salmon, after spending from one to five years in the ocean, return to their natal stream to spawn during August through December. Fish may travel hundreds of miles upstream (over 1,000 miles in the Yukon River, Alaska). Female chinook salmon select spawning sites, preferring areas of swift current, porous gravels and cool temperatures. The females construct redds, or groups of nests, in the gravel by vigorous wriggling on their sides. Salmon spawn at depths ranging from 5 to 6 inches to 3.5 feet (Reynolds et al., 1990). Females lay thousands of eggs, fertilized by the males as they are deposited, over a one to two week period. The adult salmon usually die two to four weeks after spawning, leaving the eggs and young to fend for themselves.

The eggs, in the gravel and nurtured by clean water, incubate for a period of 40 to 60 days depending on water temperature. It is essential that the gravels remain porous and clear of fine sediment so water can bring adequate supplies of oxygen to the incubating eggs and remove waste materials. The incubation stage is the period of greatest mortality. The eggs are particularly vulnerable to shock injury which can result from bottom scouring, superimposed spawning activity, low dissolved oxygen, toxic metals or chemicals, dewatering, high water temperatures, rapid or abrupt temperature changes or sedimentation. Under poor conditions egg mortality may be as high as 95 percent while under optimum conditions egg mortality may be as low as 10 percent (Reynolds et al., 1990).

At the end of the incubation period the eggs hatch and become alevins. They spend another 20 to 40 days in the gravel during which time the egg sack is absorbed and they emerge from the gravel as fry. These inch-long chinook salmon are free swimming, but seek out low-velocity back eddies and slack water areas where they feed heavily on zooplankton and small insects. Growth is usually rapid as they become fingerlings. At 2 to 3 inches long, they move downstream to the estuary or to the Pacific Ocean during spring freshets or snowmelt runoff (Allen and Hassler, 1986; Reynolds et al., 1990).

Most juvenile salmon migrate quickly to the ocean during March through June, reaching the sea at two to four months of age. Some individuals may stay many months in the downstream estuary. The San Francisco Bay/Delta Estuary is an important rearing area for Central Valley salmonids, although the extent and significance of estuarine use on the North Coast is not well-understood (DFG, 1991b). Salmon spend from one to five years in the ocean, feeding on fish and crustaceans, before migrating to their natal stream to spawn and repeat the cycle.

The fall-run chinook starts entering the various rivers usually in August and spawn in October through December. The late fall-run enters freshwater from mid-October through mid-April and spawn January through April. The winter-run migrates from mid-December through mid-July and spawn from mid-April to mid-July. Before the construction of Shasta Dam, the winter-run chinook migrated up the Pit and McCloud rivers to spawn in their cold, spring-fed waters. The spring-run was historically the most numerous in the Central Valley, with annual runs of .5 million to 1 million fish (Moyle and Yoshiyama, 1992). This run would move up the valley rivers on the spring runoff from melting snow in March through July, migrating far upstream to cooler waters where they would summer over and spawn from mid-August to mid-October. Dams have eliminated both access to upstream spawning grounds and spring flows from snowmelt runoff. Only small populations of the winter and spring runs now remain.

Unlike most chinook, steelhead and coho salmon may stay one to three years in freshwater. Juveniles require good habitat and water quality conditions throughout the year. Coho are quite sensitive to warm temperatures and typically spawn in mid-size coastal rivers and tributaries (Bell, 1985; Hassler, 1987; Shapovalov and Taft, 1954). Steelhead usually spawn in the smaller tributaries to a river or stream, and even commonly use intermittent streams. Unlike salmon, steelhead do not die after spawning and a small portion of the population may return to spawn again. (Bell, 1986; Barnhart, 1986; Shapovalov and Taft, 1954).

Native populations of anadromous salmon, steelhead and coastal cutthroat (*Oncorhynchus* spp.) are in serious decline in the Western United States—Washington, Oregon, Idaho and California. The American Fisheries Society Endangered Species Committee (Nehlsen et al., 1991) has identified 214 naturally spawning Pacific salmonid stocks threatened with extinction, of which 39 are in California. At least another 106 major populations, 21 in California, have already been lost. (See list of salmonid stocks at risk, Table 18).

The most economically important runs in the state are the Sacramento and Klamath Rivers fall-run chinook. The Klamath system chinook are also highly valued culturally by native peoples. These stocks in the last two years are not meeting the spawning escapement goals of fisheries management authorities. (Escapement is the total river run size which "escaped" ocean harvest, and is a commonly used estimator of population size. The total production = ocean catch + escapement. In any one year, escapement may be one-third to one-half total production. Spawning escapement is that portion of the river run or total escapement which is not caught inriver and is available for reproduction).

Figure 87. Fishery Biologists Monitoring Chinook.

In 1991 the total river population of the Sacramento fall-run chinook was about 110,000 fish (PFMC, 1992), compared to a peak of 403,000 in 1953, observed shortly after counts began in the river (Reynolds et al., 1990). The Klamath fall run in 1991 had a total escapement of about 31,000, only 15 percent of a recent high of 204,000 in 1987 (PFMC, 1992). Tragically, estimates of run numbers are continually becoming outdated as populations continue to collapse. The present regulatory situation is that commercial ocean harvest of chinook has been almost completely curtailed, and severe restrictions have been placed on recreational ocean and all inriver fishing, including native tribal harvest.

**Birds**

Without question, high bird species diversity and abundances are a major characteristic of California riparian habitats. The aquatic and riparian habitats of rivers are used by a broad variety of species, but river avifaunas are typically dominated by passerine species (smaller perching birds) such as flycatchers, warblers and swallows. Herons and egrets are also common along rivers, utilizing tall trees of riparian forests for rookeries, and feeding on fish and other aquatic organisms in the channel. On salmon spawning rivers in northern California, Ospreys and Bald Eagles take advantage of abundant fish for food.

Riparian woodland and forests have been noted to support a greater number of bird species than any other habitat type of the state (Miller, 1951). The importance of river riparian habitats to bird life holds true for all regions of the state, e.g. the Central Valley (Gaines, 1977; Hehnke and Stone, 1978); the South Coast (Faber et al., 1989); the Truckee and Carson rivers on the east side of the Sierra (Ridgeway, 1877, cited by Klebenow and Oakleaf, 1984), and the North Coast (Ray et al., 1984). Riparian vegetation is valuable as suitable or optimal spring/summer breeding habitat for over 120 bird species in California (CDFFP, 1988). In addition, its importance for migratory bird populations cannot be overemphasized. Fall and winter densities of migrant bird species are often two to three times greater than breeding species densities in the same riparian habitat (Michny et al., 1975; Motroni, 1984), and over ten times greater than adjacent nonriparian cover types (Stevens et al., 1977).

Many bird species, including a number at extreme risk of extinction or extirpation, have declined in response to losses of up to 95 percent of riparian vegetation in the Western U.S. In a national review of imperiled and extinct birds of the United States and Canada, Ehrlich et al., (1992) state:

> Habitat loss and degradation pose the greatest threat to North American birds. From forests to wetlands, avian

habitats are everywhere endangered. Riparian areas (corridors of water-loving vegetation along streams and rivers) are especially vulnerable and of critical importance.

Currently, at least 40 bird species on California rivers are considered to warrant special concern (see Table 17). Examples of riparian species in California which are most endangered include the Least Bell's Vireo and Western Yellow-billed Cuckoo. The following summaries are from the California Department of Fish and Game (1992).

The Least Bell's Vireo is listed both state and federally as Endangered. Once widespread in riparian forests and thickets of the Central Valley, the desert, and the Central and South Coast, it is now limited to around 300 pairs mainly in coastal southern California. It is threatened by habitat loss and nest parasitism by the Brown-headed Cowbird.

The Western Yellow-billed Cuckoo is a state Endangered species. The U.S. Fish and Wildlife Service thus far does not consider this a valid taxon for protection under the federal Endangered Species Act. This species once bred all over the state except the high Sierra, utilizing the larger stands of willow and cottonwood which it prefers. With extensive habitat loss and fragmentation of riparian habitat, by 1977 there were only an estimated 122-163 breeding pairs in California. The last census in 1986 and 1987 found only 31-42 pairs.

### Other Vertebrates

While many mammal species are not limited to stream and river ecosystems, riparian forests and woodlands provide habitat for significant concentrations of species diversity. As examples, out of 181 mammal species (excluding whales and porpoises) found in the state, Central Valley riparian communities are habitat for 55 species (Trapp et al., 1984), and in southern California, riparian habitats support 44 different mammal species (Faber et al., 1989).

The most widespread river or stream dependent mammals are river otter, beaver, mink and muskrat (Mayer and Laudenslayer, 1988). Other species with a strong dependency or preference for riparian habitats include many furbearers, such as ringtail, raccoon, mink, grey fox, red fox, coyote and skunks (Brinson et al., 1981; Stone, 1976b).

Riparian environments found on California rivers provide suitable habitat for about one-half the amphibians and one-third the reptiles found in the state (from information in Brode and Bury, 1984; and Zeiner et al., 1988, 1990a & b).

The California Red-legged Frog, once widespread in Central Valley rivers and marshes, was decimated by intensive market hunting (for the frog leg trade) in the late 1800s. The remaining limited populations are threatened by habitat loss and competition from other species. The Foothill Yellow-legged Frog has also declined in response to loss and degradation of rocky-bottom stream and river habitats, which it prefers, and interspecific competition. (See review in San Francisco Estuary Project, 1992b). Both are California Species of Concern.

See Chapter 3 for lists of common or indicative amphibians, reptiles, birds and mammals on California river systems.

## River Habitat and Community Classification

An important tool for understanding and managing rivers and streams is their classification. Classifying rivers, as well as other natural systems, is essential for making comparisons and thus inferences about them, and for communication between researchers and managers familiar with different areas and different disciplines. Most river and stream classification systems which have been developed thus far come from two different orientations: ecology vs. geomorphology, emphasizing living organisms or the physical environment, respectively. The major river classification systems which have been applied to California rivers are described below; however, no comprehensive inventory of the entire state has yet been done.

### *Ecological River Classification Systems*

For natural areas which contain significant amounts of vegetation, the dominant types of plants are commonly used as the indicator of both the environmental conditions and of the diversity and amounts of living things found there. For example, the presence of a large cottonwood dominated mixed riparian forest in the Central Valley would suggest that the environment is within the flood plain of a river or large stream, has high groundwater, and likely supports over 200 different kinds of vertebrate wildlife species in high numbers.

In scientific literature and in natural resource management there are many ways that the natural world has been described and classified, depending upon the scale and ecological characteristics of the study region, the purpose, and even the academic background and traditions of the person doing the classification. Riparian vegetation is included in numerous terrestrial vegetation classification systems at regional, state, national and even international scales. The U.S. Fish and Wildlife Service includes riparian vegetation types in a nationwide system of wetland classification (Cowardin et al., 1979), which is one of the few systems to include aquatic habitats.

Different classification schemes use different ecosystem units, different names and different decision paths. For example, a particular grouping of riparian plants might be referred to as a habitat type, natural community, vegetation type, ecosystem type, plant community, association, biotic community or cover type.

Often, a specific example or stand of vegetation will be called a habitat or community, while the class of all similar areas will be called a habitat "type" or a community "type."

Unfortunately, there is no consensus on how best to describe and classify natural systems. Resource managers and scientists must be aware of differences in looking at the world and in terminology. Explanatory "crosswalks" which list and compare classification schemes are valuable, such as the de Becker and Sweet (1988) system prepared for California vegetation types. There are at present two major trends in California for classifying habitat types.

In one program, the California Natural Diversity Data Base (CNDDB) in the Department of Fish and Game catalogues and monitors biological diversity in the state. The CNDDB currently uses a classification system of "Natural Communities" (Holland, 1986) which identifies and describes 273 upland and wetland vegetation types—86 of which are tracked as rare—including many kinds of riparian forests, woodlands and shrublands. This community classification system is undergoing a major revision by an interagency group, including staff of the CNDDB, representatives of California Native Plant Society and other vegetation scientists. With regard to aquatic habitats, the CNDDB has not yet devoted much effort at habitat identification and rare community monitoring due to limited funding. A working scheme was developed which identified freshwater, estuarine and marine community types (Ellison, 1984). Recently, Moyle and Ellison (1991), presented a new classification system for California inland freshwater habitats, based on "ichthyological provinces" (fish species distribution). This classification system has been designed to provide the basis for creating a statewide system of Aquatic Diversity Management Areas (ADMAs).

Another effort in California has focussed on classification of mainly terrestrial vegetation cover types with the primary purpose of predicting vertebrate wildlife habitat relationships. The Wildlife Habitat Relationship (WHR) System (Mayer and Laudenslayer, 1988) distinguishes only about 50 different habitat types, but these are proving useful for broadscale assessments of wildlife habitat trends as well as other forest and rangeland resources (e.g. CDFFP, 1988). Only a handful of riparian and aquatic habitat types are differentiated under the WHR system.

Another way of studying ecosystems is by taxonomic inventories. The taxonomy of living things is how they are divided into different species and other levels of phylogenetic (evolutionary) classification. Knowledge of the identity of organisms is basic to any ecological research or application. For example, if the function of a species is well-known, its presence or absence in an ecosystem can be used as an indicator of environmental conditions.

An individual species' function in an ecosystem can probably never be known completely, and for many species, it is barely known at all. Sadly, many applied environmental studies are limited to simple taxonomic inventories, rather than more involved studies of function. Such inventories are however, a critical first step. For ecosystems to survive, the assumption made by scientists today is that it is imperative "to keep all the pieces." This is the basis of the concern for preserving biological diversity. California has never comprehensively inventoried aquatic invertebrates, despite their extreme importance in aquatic food webs and as indicators of environmental quality (Erman, 1991).

### *Geomorphic River Classification*

When river and stream channels are a focus of study or management, as for restoration of fisheries or bank stabilization, geomorphic classification systems may prove useful. Classifications are useful for inventories over broad regions and for initial assessment of ecological potential or restoration needs. However, classification alone may be misleading and is insufficient alone as a basis for designing channel works (Kondolf, in prep).

Rosgen (1985) developed a classification system based on channel attributes of gradient, sinuosity, width/depth ratio, bed material size and degree of confinement. His system, currently under revision, is increasingly being used in the West. For example, the California Department of Fish and Game has incorporated Rosgen's system as a basic part of the approach for fish habitat restoration presented in their *California Salmonid Stream Habitat Restoration Manual* (Flosi and Reynolds, 1991).

## Rivers as Ecosystems—Systems of Interacting Environments and Organisms

To understand, sustain and manage natural systems it is useful to describe and categorize them as ecosystem—communities of organisms and their environments which are closely linked. Depending on purpose, ecosystem boundaries can enclose areas vastly different in size and function. For example the community of algae, microbes and insects living in a single submerged rock could be regarded as an ecosystem, as could the ten-mile stretch of river in which it is found. Even the entire biosphere of the earth can be considered an ecosystem. A new national priority is emerging for the restoration and protection of rivers as ecosystems (National Research Council, 1992).

A river ecosystem extends laterally over its entire flood plain and longitudinally from headwaters to the sea, lake or sink. A river ecosystem may even extend far beyond the flood plain to hydrologically connected aquifers. Most California river ecosystems are characterized by extreme variation over the three dimensions of space and over time.

The dynamism of rivers includes seasonal high and low flows, changes in channel and flood plain forms, and drought and flood events. Floods considered catastrophic to humans are not "disturbances" to river ecosytems. Most river biotic communities recover quickly from denudation or other mortality, and in fact large floods are beneficial for many species (National Research Council, 1992).

Rivers are considered open ecosystems; a large proportion of organic matter and nutrients comes from outside the system, especially in headwater rivers. Once in the river system, materials are continually transported downstream in a one-way flow of water. The implications of this tendency to lose materials from a particular site along a river are several: There must be a constant influx, either from terrestrial or upstream sources, of new material; there needs to be a certain amount of retention of materials at a site so that river organisms can take advantage of them; recolonization of disturbed aquatic habitats is generally from upstream; and materials tend to accumulate in downstream reaches.

Figure 88. Riparian and Aquatic Habitats.

Traditionally, stream and river biological studies make a major distinction between riparian "systems" and aquatic "systems." While from an organismal point of view it is frequently convenient to separate riparian from aquatic habitats, they should not be regarded as separate ecosystems. Riparian zones are sometimes even demoted to being called "transitional" areas or "ecotones" (boundary habitats) between upland and water. Riparian environments and biota are more than merely the edge separating dry land and water, they are integral parts of a river ecosystem. One should avoid concepts that deemphasize or ignore the tight linkages between river geomorphic and hydrologic processes, habitats, and riparian and aquatic biota.

To better appreciate the importance of the linkages between riparian vegetation, aquatic biota, and the physical/chemical environment, it is necessary to have an understanding of ecosystem functions pertaining to energy and nutrient processing in the aquatic environment. For any section of stream or river, the balance between production and consumption, and import and export, will be major determinants of the character of the aquatic community.

## *Energy and Nutrient Budgets*

A basic concept in river and stream ecology is classifying the sources of organic matter, nutrients, sediments or even pollutants entering the aquatic environment. For a particular river or stream aquatic habitat, materials which come from outside the system are termed allochthonous, and any material created or derived from inside the system is termed autochthonous. Leaves, twigs and insects from riparian vegetation which fall into the water are examples of allochthonous materials (Figure 89); benthic algal growth is an example of autochthonous production.

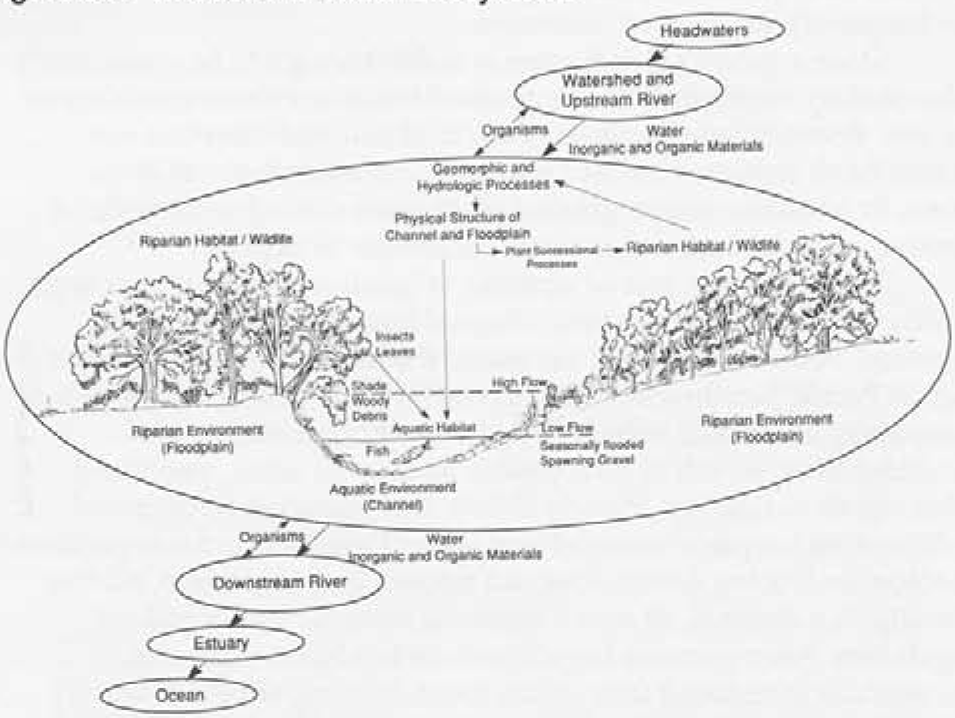
Figure 89. Leaves As Energy/Nutrient Source.

Another functional classification of aquatic habitats pertains specifically to the primary source of organic matter for use by consumers and decomposers. A river or section of river which derives most of its organic matter energy sources from primary production within the system is said to be autotrophic. A segment which is dependent upon organic material input from outside sources is said to be heterotrophic. An example of an autotrophic situation would be a reach in a medium-sized river with minimal shading and clear water, which allows for high benthic algal production. A lowland river with deep water and high amounts of turbidity limiting phytoplankton or benthic algal production would be heterotrophic (Vannote et al., 1980).

## *Ecosystem Linkages*

Discussed below are the most important linkages in river ecosystems: fluvial geomorphic processes and riparian vegetation; riparian vegetation and vertebrate animals; and riparian vegetation and aquatic habitats and food supply. Also discussed are the relationships among river ecosystems and upland/watersheds, estuarine and ocean systems and upstream-downstream variations (Figure 90).

Figure 90. Model of a River Ecosystem.




### Relationship of Fluvial Geomorphology/Hydrology and Riparian Vegetation

No other aspect of California river ecosystems is so critical yet at the same time has been so ignored in river management as the interdependence of riparian habitat and fluvial geomorphology and hydrology. The distinctiveness of riparian forests and woodlands and their high value for fish and wildlife habitat is largely due to the physical environments created by natural river processes.

Flood plain landforms present subtle but important variation in topography and substrate texture. The height, shape and soil characteristics of river landforms combine with groundwater and surface water regimes to create unique plant environments. Species will predictably segregate in space over these different environments, and therefore riparian vegetation patterns can be used as indicators of hydrogeomorphic conditions (Hupp and Osterkamp, 1985).

For alluvial or meandering rivers, variation of river landforms over time is as significant to riparian vegetation as spatial variation. As described in the previous section on plants, riparian vegetation successional processes must proceed in order to perpetuate the mosaic of riparian habitats. Without flooding, erosion and deposition, the large forests of riparian vegetation along valley rivers cannot be maintained naturally.

For constrained reaches, for example in narrow mountain valleys, riparian vegetation is less dependent in a positive way upon physical river processes, and is generally in a battle just to survive the frequently scoured environment.

Once a geomorphic feature is stable enough to be successfully colonized by vegetation, the vegetation tends to enhance stability of the site. Roots enhance tensile strength of soil and therefore can reduce bank erosion, at least up to a certain magnitude of shear stress. In addition, above-ground plant parts can act to slow flood currents, which in turn may cause sediments to deposit.

The important role of riparian vegetation as a source of large woody debris within the active channel has only recently been explored. Sedell et al. (1988) reviewed the many functions of fallen logs in Pacific Northwest rivers. Coarse woody debris increases the complexity of aquatic habitats by physically obstructing and diverting flow, which in turn creates backwater areas, pools and other depth variability. Woody debris also increases retention of sediment and organic material and is itself a substrate for organisms to colonize. During floods, logs can protect live vegetation, adding stability to a channel, or act as battering rams on banks and vegetation. After extreme large floods or landslides, channel equilibrium is restored faster with the stabilizing effects of woody debris. In rivers originating in heavily timbered and mountainous watersheds, it is not uncommon for instream coarse, woody debris to come from upland as well as streamside forests.

### Relationship of Riparian Habitat and Vertebrate Wildlife

Riparian vegetation is of extreme value as habitat for vertebrate wildlife species. Throughout the United States, riparian habitat has been shown to support a greater diversity and abundance of wildlife than practically any other cover type (see extensive review of previous studies by Brinson et al., 1981). Riparian habitats are characterized especially by a rich bird life.

Attributes of riparian vegetation which relate to its importance as wildlife habitat include (from Brinson et al. 1981): predominance of woody plant communities (trees and shrubs); presence of surface water and soil moisture; diversity and interspersion of habitat features; and role as corridors for dispersal and migration.

For California, a major distinguishing feature of riparian vegetation is the dominance by mesic deciduous species. Their copious transpiration, succulent leaves and high productivity create a virtual greenhouse environment (Roberts et al. 1977) in contrast with adjacent upland areas.

Riparian habitat in California is best developed along larger meandering rivers. As described previously, the geomorphic processes of erosion, deposition and meander influence plant succession processes. Areas on higher flood plain terraces which grow into mature gallery forests represent the most productive habitat in the state. Such riparian forests have a highly complex structure, with a high tree top canopy, many understory layers, often a thick ground layer, and a profusion of vines hanging in lianas from the uppermost forest strata to the ground. This dense and diverse vegetation provides a large variety and quantity of animal living requirements including nesting and perching opportunities; food from seeds, fruits, and insects; and a shady, cool and moist microclimate. Riparian habitat supports many smaller birds, mammals, reptiles and amphibians which in turn are prey to larger vertebrates.

Often, different successional stages of riparian vegetation are important to different wildlife species. For example, the Willow Flycatcher prefers willow thickets, an early stage in riparian vegetation succession. Cavity nesters such as woodpeckers require large trees with broken canopies such as might be found in older sycamores or oaks.

While vegetation is the most important feature determining the value of riparian zones for vertebrate wildlife habitat, it is not the only one. For certain species, the physical characteristics of the substrate textures and land forms are critical components of their habitat. For example, most of California's remaining population of the Threatened Bank Swallow nest on eroding sandy banks of the Sacramento River and tributaries. Without the continuing meander of the river, survival of this species is in doubt (DFG, 1992). Killdeer are ground-nesting and -feeding birds which are common along river shores. Killdeer rely on camouflage for protection of adults as well as nests, and river gravel bars provide excellent concealment.

## Relationship of Riparian Vegetation and Aquatic Communities

Riparian vegetation is a major influence on aquatic communities in streams and rivers by physically altering the habitat, by affecting inputs of dissolved and particulate organic and inorganic substances, and by providing terrestrial habitat for prey and predators of aquatic organisms. The close interrelationship of riparian vegetation and aquatic habitats has been reviewed by many, e.g. Baltz and Moyle (1984); Gregory et al. (1991); Knight and Bottorf (1984); and Meehan et al. (1977). Their description of ecosystem functions, both conceptual and quantified, are summarized on the next page.

Riparian vegetation, through influences on channel and flood plain geomorphology (as described above) often plays a major role in shaping the structure of the underwater habitat. Submerged roots, branches and trunks usually enhance the productivity of a stream or river reach, particularly for fish.

Riparian vegetation can alter instream temperatures by shading water from solar radiation. The presence of vegetation, especially a thick tree canopy, can also reduce daily temperature fluctuations compared to an open stream. The temperature-moderating effects of riparian vegetation are strongest with smaller streams. On very large rivers, such as the Sacramento River, the effect of adjacent riparian habitat on overall water temperature becomes minimal.

Riparian vegetation is a major source of primary production for streams. In headwater areas, the input of allochthonous plant material provides most of the base of the aquatic food chain. Coarse leaf and twig material is broken down in the stream by insects and microbes into fine and dissolved organic matter which is consumed onsite or transported downstream.

In lowland reaches, primary production is a combination of phytoplankton growth and the input of fine and dissolved substances which originated upstream. In downstream reaches, the riparian vegetation immediately adjacent is less important for the energy balance of the whole river than for headwater areas.

Figure 91. Shaded Riverine Aquatic Cover.

The input of dissolve inorganic substances draining from upland sources into the water is controlled to a large extent by intervening riparian vegetation. Riparian trees and shrubs take up large quantities of nutrients and thus can alter the amount reaching the aquatic environment.

Along the Sacramento River system, the specific importance of riparian vegetation lining the banks has recently been observed and evaluated by the U.S. Fish and Wildlife Service (DeHaven, 1989). Shaded Riverine Aquatic Cover (SRA) is the habitat formed by the interface between woody riparian vegetation and the water. Overhanging branches, submerged roots and irregular crevices and surfaces of natural banks provide shade, cover and food supply to the immediate nearshore environment of large rivers.

SRA cover along the Sacramento River benefits numerous wildlife and fish species, including river otter, beavers, herons, egrets, kingfisher and salmonids. The extreme value of SRA cover has been demonstrated in studies and observations on juvenile salmonids. Higher densities of juveniles occur along natural banks than along those which are riprapped (armored with rock) and lacking SRA cover (DeHaven, 1989). The shaded environment created along the banks by SRA cover is considered critically important in the lower river, where water temperatures can heat to over 70°F. As of July 1992, 70 percent of the banks have been riprapped in the lower 60 miles of the Sacramento River and adjacent sloughs (Storfer, 1992). Because of the extremely high habitat value, scarcity and threatened future of SRA cover, this has recently been determined to be Resource Category 1, i.e. unique and irreplaceable, by the Regional Office of the Fish and Wildlife Service (Memorandum signed by Marvin Plenart, Regional Director, Portland; September 21, 1992).

**Relationship of Rivers to Upland/Watershed**

The influence of watershed condition and rivers and streams is readily observable when watersheds are artificially disturbed (Debano and Schmidt, 1989). Timber harvest, grazing and urbanization can significantly alter downstream waterways. The removal of vegetation, the construction of roads and alterations of the drainage network can lead to increased runoff and higher flood peaks, significant land erosion and reduced water retention for later release. Stream and river channels are subjected to flashier, sediment-laden flows during storms and decreased base flows in the dry season. Channels become unstable, with increased bank erosion, and riparian and aquatic habitats are destroyed or damaged, with almost no potential of easy recovery.

As noted above, the amount and character of dissolved nutrients draining from the land into the water is influenced by riparian vegetation. Riparian forests can remove dissolved nutrients such as nitrates and phosphates and particulate organic matter from upland surface and ground water before they drain to river waters. This filtering by riparian vegetation is potentially significant in reducing nonpoint source pollution from agricultural sources (Peterjohn and Correll, 1984).

## Relationship of Rivers to Estuaries and the Ocean

Estuaries are enclosed bodies of water where fresh water from land meets salt water from the sea. Estuaries are among the most productive ecosystems in the world, supporting abundant shellfish, fish and bird life. Healthy estuarine ecosystems result in large part from the unique circulation patterns created by the mixing of salt and freshwater, and from large influxes of nutrients from streams and rivers. River and stream flow amounts and timing are thus critical determinants of the character of estuaries.

Because estuaries are at the receiving end of whatever is transported by their tributary waterways, they are vulnerable to significant impacts caused by upstream alterations to rivers and streams. The most severe problems in California estuaries include decreases in freshwater input or changes in flow timing, excess sedimentation and chemical pollutants.

An overview of California's estuaries can be found in the *California Comprehensive Offshore Resource Study (Draft)* by the State Lands Commission (1991). Reports on the status and trends of the San Francisco Bay/Delta Estuary, the largest estuarine ecosystem on the West Coast, include *The State of the Estuary (1992), Status and Trends Report on Aquatic Resources in the San Francisco Estuary (1992), Status and Trends on Wetlands and Related Habitats of the San Francisco Estuary (1991), Status and Trends Report on the Wildlife of the San Francisco Estuary (1922),* by the San Francisco Estuary Project; *Ecology of the Sacramento-San Joaquin Delta: A Community Profile* (Herbold and Moyle, 1989); and *Delta-Estuary: California's Inland Coast,* by the State Lands Commission (1991).

Materials transported by rivers also affect the ocean, the ultimate sink for most of California's natural waterways. As with estuarine systems, chemical pollutants from river runoff are a major problem for nearshore ocean environments. One of the most notorious examples of runoff effects on marine resources is the near extinction of the California Brown Pelican from eggshell thinning caused by DDT, a once commonly used pesticide (now banned).

Sediment transported by rivers and streams in California is the major source of sand for most of the state's ocean beaches (Griggs et al., 1992). Human activities on coastal rivers which interrupt natural geomorphic and hydrologic processes, such as upstream dams, settling basins and flood control projects, have reduced natural sand replenishment to eroding beaches (California State Lands Commission, 1991).

A major linkage between rivers and estuaries and the ocean is through anadromous fish. Pacific salmon and steelhead connect headwater areas, valley rivers, estuaries, and the high seas of the Pacific Ocean. Habitat damage and overharvest can equally affect fish populations. In the past, uncontrolled in river fishing, and then later ocean fishing, seriously depleted salmon stocks which led ultimately to tight regulations. Early mining and logging also took their toll, but populations could usually rebound once fishing pressure was reduced. Today, diversions and other habitat impacts are so severe that recovery from the recent dry cycle seems problematic. In response to the desperate prognosis for California anadromous salmonids, the Pacific Fishery Management Council (PFMC) and California Department of Fish and Game have all but eliminated ocean fishing and, in some places, in river fishing as well.

**Upstream-Downstream Variation**

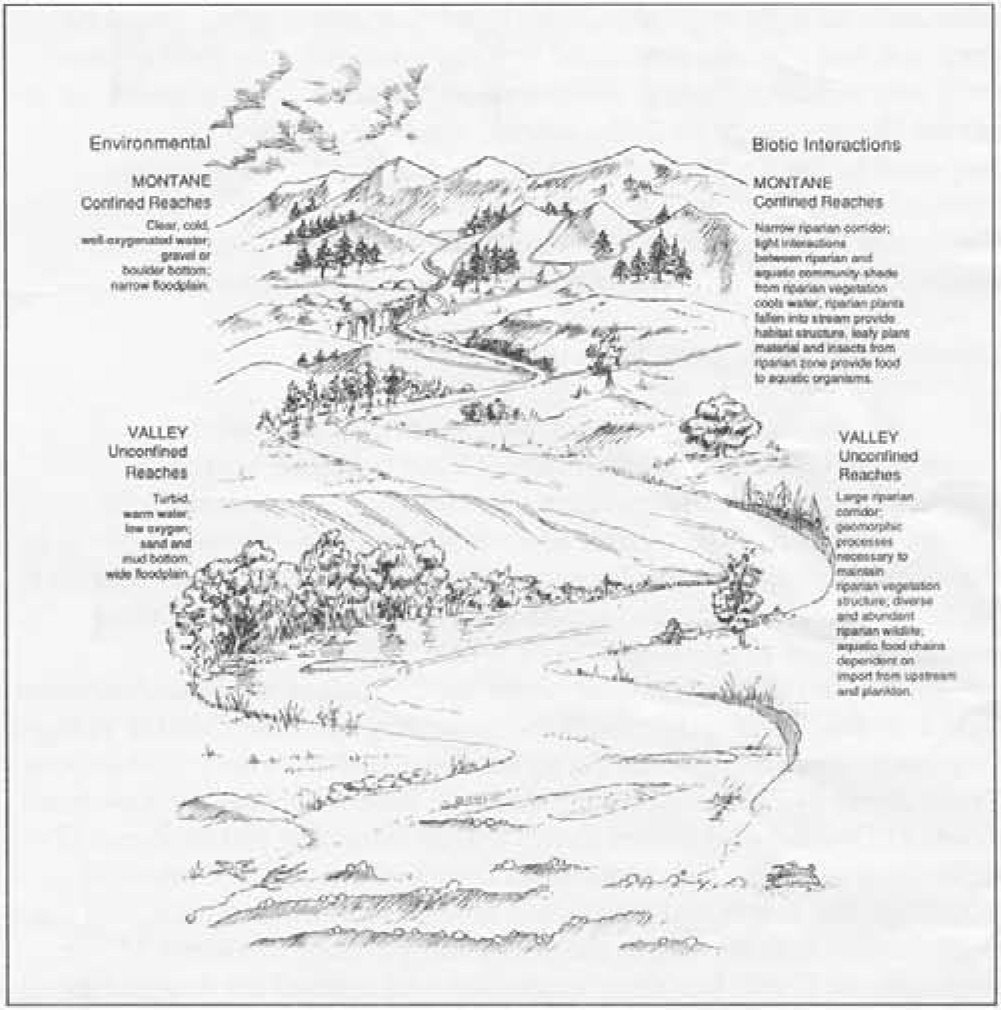
A river changes as it flows from headwaters to mouth. Environmental factors—flows, channel form, substrate texture, temperature and other parameters of water quality —vary along its course. The distribution of river organisms responds to these gradients in the environment, often resulting in recognizable zones. Aquatic species in particular have been studied world-wide to attempt to classify river reaches or zones (See Hawkes, 1975; Hynes, 1970).

Moyle (1976) identified zones for California rivers and streams based on fish species distribution. For example, in the Central Valley, five zones were recognized (in up-to downstream order): 1) Rainbow Trout Zone; 2) California Roach Zone; 3) Squawfish-sucker-hardhead Zone; 4) Deepbodied Fishes Zone; and 5) Estuarine Fishes Zone. The trout zone is in the high mountains (much extended as a result of planting), the roach and squawfish zones are in the foothills, and the deep-bodied fish zone is in the valley flat portions of rivers. Moyle, with Ellison, (1991) has since expanded and refined his description of fish zones, in the new classification system for inland waters discussed elsewhere in this chapter.

Rivers are difficult to classify for the purposes of study and management because of their differences. However, it is instructive to consider rivers in two major zones, upstream and downstream, as first identified by Illies (various papers; refer to Hawkes, 1975, p. 366; Hynes, 1970, p. 392). A large number of the differences between upstream and downstream reaches are similar for most California rivers as well as many temperate-region rivers world-wide, shown in Figure 92.

Despite the ease and convenience of classifying and studying rivers by zone, it is closer to reality to recognize that environmental factors and biotic responses change over upstream-downstream gradients. Stream and river ecology in the last few decades has attempted to explain changes in the ecosystem functions of the aquatic community along these gradients. The River Continuum Concept (Vannote et al. 1980) holds that there is a more or less predictable gradient of environmental factors—flow regime, water temperature, solar radiation and others—from headwaters to downstream large river reaches. Aquatic energy and nutrient processing

Figure 92. Upstream/Downstream Variation in Rivers.




also vary in a predictable way in response to environmental gradients as proposed in the concept.

For example, this concept generalizes that smaller headwater reaches are highly dependent upon allochthonous sources of coarse organic matter, which decreases downstream in importance. The aquatic biota in headwater areas is predicted to be dominated by shredders and collectors such as caddisflies, with little algal growth.

Such predictions have been shown to be true for many streams, generally those originating in heavily forested regions. However, the pattern of change in ecosystem functions along river continua is not the same for all streams. In contrast to forested areas, headwater desert streams may have high instream primary productivity and less reliance on allochthonous material (Minshall, 1978; and Minshall et al., 1989). Upstream-downstream gradients are rarely smooth; the environments and living resources vary between short patches, such as pool/riffle sequences (Schlosser, 1982).

These advances in ecological concepts are being refined and tested in field research, which will improve predictive abilities. This type of knowledge should be applied to solving difficult problems of river management, but as yet is not (Karr, 1991).

## River Biodiversity

### *What All This Means*

This California landscape, lying over a broad range of climates, soils and topography, yields an exceptional diversity of terrestrial, freshwater and estuarine plants, animals and natural communities, including species dependent upon river habitats. The survival of these diverse and interdependent systems is threatened by human population growth, land and water development and environmental deterioration of water and air quality. Protection of biological diversity, or biodiversity, is the key to survival for all ecosystems.

Biodiversity is the variation in living resources at all levels of organization, including genes, species, communities and landscapes. Species diversity, which is all the different kinds of plants and animals in an area, is relatively easy to conceptualize. Equally important, although harder to study and understand, are the smaller and larger scales of variation in the gene pools of populations or species, and variation in habitats and ecosystems over extensive landscape regions.

Michael Barbour, a U.C. Davis botanist, wrote in *California's Changing Landscapes* . . . "of the world's ten major soils, California has all 10. As many as 375 distinctive natural communities have been recognized in the state." More than 5,000 kinds of native ferns, conifers and flowering plants have been identified. Japan, which is similar in area to California, has far fewer species; nor does Alaska match California's plant diversity. "Moreover, about 30 percent of California's native plants are found nowhere else in the world."

### *Status of Biodiversity*

The significant loss of natural diversity in California in the last 150 years is alarming. These losses are partly caused by direct commercial exploitation of certain species and partly by the effects of human population growth and modern technology. In the last 200 years, numerous plants and animals have become extinct or have been eliminated from the state, including the thicktail chub, once one of the most common fishes of the Central Valley lowland rivers and Delta, and the grizzly bear, California's state mammal.

In California, freshwater-based natural systems are the most damaged of all ecosystems (Jensen et al., 1990; Mooney et al., 1986). The state's rivers have been distressed more than any other aquatic resource. No pristine rivers are left. This is dramatically indicated by the long lists of declining and threatened species associated with rivers seen in Table 17 at the end of this chapter.

Internationally, aquatic ecosystems are experiencing significant problems of biodiversity loss and threats, as evidenced by freshwater fish fauna, the best studied of aquatic biota. A conservative estimate is that 20 percent of freshwater fish worldwide are extinct or are seriously threatened (Moyle and Leidy, 1992).

Biodiversity of California rivers is threatened by a battery of impacts: vegetation clearing; altered hydrology, sedimentation and erosion processes; channelization; watershed land use practices; flood plain development; pollution; native species overharvest; and exotic species introductions. (For discussion of many of these impacts see Chapters 1 and 2.)

These impacts of human activity have degraded (or eliminated) ecosystem *parts*—species populations and habitats; and interrupted natural ecosystem *processes*—flooding, erosion, and plant succession. Natural communities have become increasingly fragmented, with the result that species and habitats may no longer be self-sustaining within a region. This is especially true for riparian communities, which have been shrunken into narrow corridors and broken up along the lengths of river reaches.

Such fragmentation of riparian communities adversely affects river dependent species and has major impacts on other species by destroying corridors between habitat areas. In many parts of the state, so much natural area is gone that the remaining small pieces of habitat left can only function if they can be connected to other small pieces through corridors for migration, recolonization and other movements of living resources. Continued exchange of genetic information is a major benefit of such connections. Riparian areas offer probably the single best opportunity for creating and maintaining habitat corridors (Harris and Gallagher, 1989).

Another significant threat to biodiversity is the introduction of nonnative species. California's flora and fauna have been drastically altered over the last two centuries by the establishment of exotic plant and animal species. Although the ecology of invasion varies by individual species and environments, generally those ecosystem types which have suffered the greatest artificial disturbance are the most susceptible to successful invasions of plants and animals (Mooney et al., 1986). Rivers are among the most altered ecosystems in the state and most riparian and aquatic communities have been damaged by species introductions.

Major nonnative plant species which threaten riparian communities include Jubata (Pampas) grass, tree-of-heaven, fig, false-bamboo and salt cedar (tamarisk). These plants are capable of spreading quickly over large areas to the exclusion of native riparian plant species. The habitat values provided by these species is generally lower than that for the natural vegetation, and these weedy species often cause problems for other aspects of river and stream management such as flood channel maintenance.

Introductions of exotic fish species are often accompanied by declines and disappearances of native species. It may be that native species cannot compete or cannot escape predation. Introductions usually accompany other environmental changes so that it is difficult to tell the cause of native species declines (Moyle, 1986). Introduced species into California rivers include the striped bass and American shad, two popular anadromous game fishes, and many warm water species such as catfish, sunfishes and basses.

The African clawed frog on the South Coast and bull frogs throughout the state threaten native amphibians, as well as invertebrates and fish (Faber et al., 1989; Moyle, 1973).

Brown-headed cowbirds, parasitic in other bird species' nests, formerly were found only in the far eastern part of the state. With the development of extensive agriculture and other intensive land uses they have dramatically extended their range and numbers. This species is having devastating effects on many bird species, including the Endangered Least Bell's Vireo (Zeiner et al., 1990).

## *Trends in Protection of Biodiversity*

Preserving areas in their natural states is the most effective way to maintain biological diversity (U.S. Congress, Office of Technology Assessment, 1987). Numerous areas in California have been given official protection to preserve natural ecosystems, provide habitat for rare or endangered species, safeguard scenic areas, maintain open space or provide recreation in undeveloped areas. However, the protection of aquatic habitats in reserves has not been done on any significant scale.

Aquatic community preservation presents a difficult challenge. Activities on surrounding watersheds or in upstream reaches of water bodies have as much to do with the condition of a river, lake or estuary as uses onsite. Furthermore, larger waterways have traditionally been important for navigation and other commercial uses. For example, although the larger North Coast rivers have been placed under protection in the state and federal Wild and Scenic River systems, many reaches of these rivers have been significantly affected by logging, mining and other development activities.

## *Aquatic Diversity Management Areas*

A scheme for protecting aquatic diversity in California has been proposed by Peter Moyle (Moyle and Ellison, 1991; Moyle and Yosiyama, 1992). The proposed framework is based upon inventory and classification of aquatic habitats and organisms in order to establish a system of protected Aquatic Diversity Management Areas (ADMAs). At present, taxonomic and genetic data is lacking for many species, and cataloging of aquatic habitats has just begun. The CNDDB in the Department of Fish and Game is incorporating diversity data using the community classification system developed by Moyle and Ellison.

## *Restoration*

Unfortunately, the preservation of remaining natural areas is in itself not enough to ensure biological diversity, due to the scarcity and fragmentation of relatively pristine systems. Species and community restoration of damaged ecosystems is also necessary for long-term protection of biodiversity, especially for aquatic ecosystems. The National Research Council (1992) has recommended that a national strategy for the restoration of rivers and other aquatic ecosystems be developed, with a target of restoring at least 400,000 miles of river ecosystems within the next 20 years.

In California, many riparian restoration projects have been implemented, but most are on a relatively small scale, rather than for whole systems (See Chapter 5). Riparian and stream restoration projects are undertaken for a variety of reasons, including streambank stabilization, fisheries improvement, recreation or project mitigation. They may be carried out by local cities or counties, public interest groups, government agencies or private developers. Projects in southern California have been mostly for development mitigation purposes, while the projects in the central and northern counties are undertaken for streambank stabilization and fisheries enhancement.

A large number and variety of projects to help return fish populations to historic levels in California have been attempted. Both habitat restoration projects and the artificial propagation of fish, primarily through hatcheries, are used. Habitat restoration projects involve modifications to disturbed areas in an attempt to return them to a more natural and useable state. These modifications include placing structures in streams (rootwads, trees, etc.) to increase fish habitat and cover, removing migration barriers such as log jams, revegetation and stabilizing landslides.

Small-scale artificial propagation of native stocks is often utilized with good success to boost natural populations. Several American Indian tribes rear salmon on a small scale for the enhancement of local populations, as do a number of private fishing and conservation groups and some school programs. These grassroots efforts are probably quite valuable in keeping small individual stocks healthy, thus helping to maintain genetic diversity.

While large hatcheries are often used to produce fish, especially for water project mitigation, they are not nearly as significant as natural spawning. Hatchery fish account for only 11 percent of all the fall-run chinook salmon in the Central Valley and 19 percent of the Klamath run. In addition, fishery biologists are seriously concerned with the effect of hatcheries on the genetic diversity of natural populations (Higgins, 1991). In the long run, hatcheries may weaken the genetic make-up of wild stocks so that they can no longer survive the extreme variability of environmental conditions found in the natural world. Many of the over 200 Pacific salmonid stocks found at risk for survival, including a number from California, are threatened in part by genetic contamination from artificial propagation (Nehlsen et al., 1991). Other problems with hatcheries include the potential for intraspecific competition and disease which can harm the wild stocks, as well as the possibility for human error.

While site-specific restoration programs for fisheries and riparian habitat are important as stopgap measures, the key to truly effective aquatic ecosystem restoration is through integrated restoration of whole landscape units (National Research Council, 1992). With river systems, in most cases restoration will need to be based on watersheds.

In California, as well as in other states, there is a growing movement toward cooperative watershed associations. These watershed associations (often called watershed councils or alliances) may involve private landowners, government, resource users and citizens' groups. The point of such associations is to bring together all parties with a stake in restoring and managing watersheds and waterways to find solutions to problems through consensus.

Figure 93. Living Resources of the River.

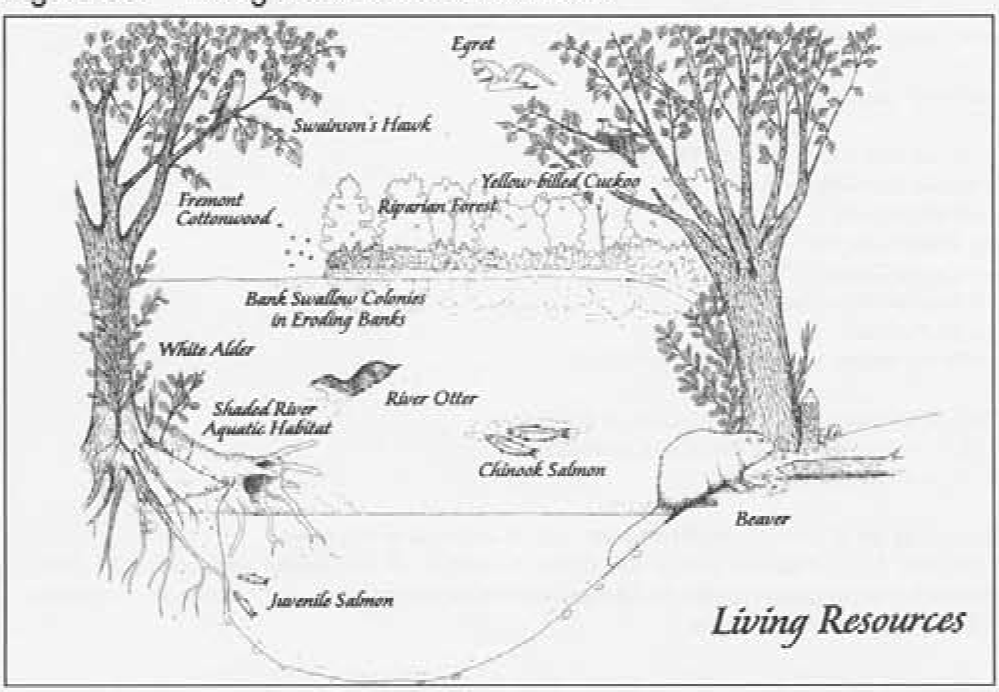


Table 17. Special Species of California's Rivers.

**SPECIAL PLANTS OF CALIFORNIA'S RIVERS**

| | Status | Distribution by Region+ |
|---|---|---|
| Suisun Marsh Aster *Aster chilenseis lentus* | FC | NC,CV |
| Spring-loving Centaury *Centaurum namophilum namophilum** | FT | D |
| Slough Thistle *Cirsium crassicaule* | FC | CV |
| Suisun Thistle *Cirsium hydrophilum hydrophilum* | FC | NC |
| La Graciosa Thistle *Cirsium loncholepis* | ST,FC | CC |
| Flaming Trumpet *Collomia rawsoniana* | FC | CV |
| Soft Bird's Beak *Cordylanthus mollis mollis* | SR,FC | NC,CV |
| Slender-horned Spineflower *Dodecahema leptoceras* | SE,FE | SC |
| Santa Ana River Woolly Star *Eriastrum densifolium sanctorum* | SE,FE | SC |
| Delta Button Celery *Eryngium racemosum* | SE,FC | CV |
| Ash Meadows Gumplant *Grindelia fraxino-pratensis* | FT | D |
| Mojave Tarplant *Hemizonia mohavensis* | SE,FC | D |
| California Hibiscus *Hibiscus californicus* | FC | CV |
| Delta Tule Pea *Lathyrus jepsonii jepsonii* | FC | NC,CV |
| Mason's Lilaeopsis *Lilaeopsis masonii* | SR,FC | NC,CV |
| Northern California Black Walnut *Juglans hindsii hindsii* | FC | CV |
| Truckee Barberry *Mahonia sonnei** | SE,FE | ES |
| Abbott's Bushmallow *Malacothamnus abbottii* | CNPS1A,FC | CC |
| Willowy Monardella *Monardella linoides viminea* | SE,FC | SC |
| Amargosa Nitrophila *Nitrophila mohavensis* | SE,FE | D |
| Santa Lucia Mint *Pogogyne clareana* | SE,FC | CC |
| Narrow-leaved Cottonwood *Populus angustifolia* | CNPS 2 | ES,D |
| Valley Oak *Quercus lobata* | CNPS 4 | NC,CV,CC |
| Parish's Gooseberry *Ribes divaricatum parishii* | FC | SC |
| Del Norte Willow *Salix delnortnesis* | CNPS 4 | NC |
| Owens Valley Checkerbloom *Sidalcea covillei* | SE,FC | ES |

* Taxonomic status in question

**+ Regions** (see Map of Regions, Figure 69)
NC = North Coast/Klamath
CV = Central Valley
Mo = Modoc/Cascade
CC = Central Coast
ES = Eastside/Great Basin
SC = South Coast
D = Desert (Mainly represents Colorado River)

SR,ST,SE = State listed rare, threatened, or endangered
FT,FE = Federally listed threatened, or endangered
FC = Federal candidate

Above plants are all Calif. Native Plant Society List 1B unless otherwise noted
CNPS Lists: 1A = Presumed extinct; 1B = Rare, threatened, or endangered everywhere; 2 = Rare, threatened, or endangered in California but more common elsewhere; 3 = Review - need more information; 4 = Watch - limited and vulnerable

Sources: DFG (1992a), Jepson Manual (1993), Smith and Berg (1988)
DFG Natural Diversity Data Base Special Plants List, August 1991.

Continued on next page.

Table 17. Continued.

| SPECIAL ANIMALS OF CALIFORNIA'S RIVERS | Status | Distribution by Region + |
|---|---|---|
| **Invertebrates** (Listed species only) | | |
| Valley Elderberry Longhorn Beetle *Desmocerus caifornicus dimorphus* | FT | CV |
| Trinity Bristle Snail *Monadenia setosa* | ST,FC | NC |
| Shasta Crayfish *Pacifastacus fortis* | SE,FE | Mo |
| California Freshwater Shrimp *Syncaris pacifica* | SE,FE | NC |
| **Amphibians** | | |
| Tailed Frog *Ascaphus truei* | CSC | NC,Mo |
| Colorado River Toad *Bufo alvarius* | CSC | D |
| Arroyo Southwestern Toad *Bufo microscaphus californicus* | CSC,FC | CC,SC |
| Arizona Southwestern Toad *Bufo microscaphus microscaphus* | FC | D |
| Del Norte Salamander *Plethodon elongatus* | CSC,FC | NC |
| Northern Red-legged Frog *Rana aurora aurora* | CSC,FC | NC,Mo |
| California Red-legged Frog *Rana aurora draytonii* | CSC,FC | NC,CV,Mo,CC,SC |
| Foothill Yellow-legged Frog *Rana boylii* | CSC,FC | NC,CV,Mo,CC,SC |
| Mountain Yellow-legged Frog *Rana muscosa* | CSC,FC | CV,SC |
| Leopard Frog *Rana pipiens* | CSC | ES,D |
| Olympic Salamander *Rhyacotriton olympicus* | CSC | NC |
| Couch Spadefoot *Scaphiopus couchii* | CSC | D |
| Coastrange Newt *Taricha torosa torosa* | CSC | NC,CC,SC |
| **Reptiles** | | |
| Northwestern Pond Turtle *Clemmys marmorata marmorata* | CSC,FC | NC,CV,Mo |
| Southwestern Pond Turtle *Clemmys marmorata pallida* | CSC,FC | CV,CC,SC |
| Sonoran Mud Turtle *Kinosternon sonoriense* **EXTINCT?** | CSC | D |
| Alameda Whipsnake *Masticophis lateralis euryxanthus* | ST,FC | CC |
| Giant Garter Snake *Thamnophis gigas* | ST,FPE | CV |
| **Birds** | | |
| Cooper's Hawk *Accipiter cooperi* | CSC | NC,CV,Mo,CC,ES,SC,D |
| Northern Goshawk *Accipiter gentilis* | CSC,FC | NC,CV,Mo,ES |
| Sharp-shinned Hawk *Accipiter striatus* | CSC | NC,CV,Mo,CC,ES,SC,D |
| Tricolored Blackbird *Agelaius tricolor* | CSC,FC | CV,Mo,CC,SC |
| Great Blue Heron *Ardea herodias* | SpA | NC,CV,Mo,CC,ES,SC,D |
| Long-eared Owl *Asio otus* | CSC | NC,CV,Mo,CC,ES,SC,D |
| Aleutian Canada Goose *Branta canadensis leucopareia* | FT | NC,CV |
| Ruffed Grouse *Bonasa umbellus* | CSC | NC |
| Barrow's Goldeneye *Bucephala islandica* | CSC | NC,CV,CC |
| Swainson's Hawk *Buteo swainsoni* | ST | CV,MO,(CC),ES,(SC) |
| Northern Cardinal *Cardinalis cardinalis* | CSC | D |
| Great Egret *Casmerodius albus* | SpA | NC,CV,Mo,CC,SC,D |
| Western Yellow-billed Cuckoo *Coccyzus americanus occidentalis* | SE | (NC),CV,Mo,CC,SC,D |
| Gilded Northern Flicker *Colaptes auratus chrysoides* | SE | D |
| California Yellow Warbler *Dendroica petechia brewsteri* | CSC | NC,CV,Mo,CC,ES,SC,D |
| Sonora Yellow Warbler *Dendroica petechia sonorana* | CSC | D |
| Reddish Egret *Egretta rufescens* | FC | SC |
| Snowy Egret *Egretta thula* | SpA | NC,CV,Mo,CC,ES,SC,D |

Continued on next page.

Table 17. Continued.

| Birds, continued | Status | Distribution by Region + |
|---|---|---|
| Willow Flycatcher *Empidomax traillii* | SE | (NC),(Mo),CV,(CC),SC |
| Southwestern Flycatcher *Empidomax traillii extimus* | SE,FC | SC |
| American Peregrine Falcon *Falco peregrinus anatum* | SE,FE | NC,CV,Mo,CC,ES,SC,D |
| Bald Eagle *Haliaeetus leucocephalus* | SE,FE | NC,CV,Mo,CC,ES,SC,D |
| Harlequin Duck *Histrionicus histrionicus* | CSC,FC | CV and along coast |
| Yellow-breasted Chat *Icteria virens* | CSC | NC,CV,Mo,CC,ES,SC,D |
| Western Least Bittern *Ixobrychus exilis hesperis* | CSC,FC | CV,Mo,ES,SC,D |
| California Black Rail *Laterallus jamaicensis coturniculus* | ST,FC | CV,D |
| Gila Woodpecker *Melanerpes uropygialis* | SE | D |
| Elf Owl *Micrathene whitneyi* | SE | D |
| Brown-crested Flycatcher *Myiarchus tyrannulus* | CSC | D |
| Black-crowned Night Heron *Nycticorax nycticorax* | SpA | NC,CV,Mo,CC,ES,SC,D |
| Osprey *Pandion haliaetus* | CSC | NC,CV,Mo,CC,ES,SC,D |
| Black-capped Chickadee *Parus atricapillus* | CSC | NC |
| Double-crested Cormorant *Phalacrocorax auritus* | CSC | NC,CV,Mo,CC,SC |
| Summer Tanager *Piranga rubra* | CSC | D |
| Purple Martin *Progne subis* | CSC | NC,CV,Mo,CC,ES,SC |
| Vermilion Flycatcher *Pyrocephalus rubinus* | CSC | |
| Yuma Clapper Rail *Rallus longirostris yumanensis* | ST,FE | D |
| Bank Swallow *Riparia riparia* | ST | NC,CV,Mo,CC,ES,(SC) |
| Crissal Thrasher *Toxostoma dorsale* | CSC | D |
| Arizona Least Bell's Vireo *Vireo bellii arizonae* | SE | D |
| Least Bell's Vireo *Vireo bellii pusillus* | SE,FE | (CV),CC,SC |

| Mammals | | |
|---|---|---|
| Sierra Nevada Mountain Beaver *Aplodontia rufa californica* | CSC | CV |
| White-footed Vole *Arborimus albipes* | CSC,FC | NC |
| Mexican Long-tongued Bat *Choeronycteris mexicana* | CSC,FC | SC |
| Spotted Bat *Euderma maculatum* | CSC,FC | ES,SC,D |
| Yuma Mountain Lion *Felis concolor browni* | CSC,FC | D |
| California Wolverine *Gulo gulo luteus* | ST, FC | NC,CV,Mo,ES |
| Oregon Snowshoe Hare *Lepus americanus klamathensis* | CSC | NC,Mo |
| Sierra Nevada Snowshoe Hare *Lepus americanus tahoensis* | CSC | CV |
| Southwestern River Otter *Lutra canadensis sonorae* | CSC,FC | D |
| California Leaf-nosed Bat *Macrotus californicus* | CSC,FC | D |
| Pacific Fisher *Martes pennanti pacifica* | CSC,FC | NC,CV,Mo |
| Mohave Vole *Microtus californicus mohavensis* | CSC,FC | D |
| Amargosa Vole *Microtus californicus scirpensis* | SE,FE | D |
| Owens Valley Vole *Microtus californicus vallicola* | CSC,FC | ES |
| Arizona Myotis *Myotis lucifugus occultus* | CSC,FC | D |
| Cave Myotis *Myotis velifer brevis* | CSC,FC | D |
| Riparian Woodrat *Neotoma fuscipes riparia* | CSC,FC | CV |
| Pocketed Free-tailed Bat *Nyctinomops femorosaccus* | CSC | D |
| Pacific Pocket Mouse *Perognathus longimebris pacificus* | CSC,FC | SC |
| Pale Big-eared Bat *Plecotus townsendii pallescens* | CSC | NC,CV,Mo,CC,ES,SC,D |
| Townsend's Big-eared Bat *Plecotus townsendii townsendii* | CSC,FC | NC,CC |
| Colorado River Cotton Rat *Sigmodon arizonae plenus* | CSC,FC | D |
| Yuma Cotton Rat *Sigmodon hispidus eremicus* | CSC,FC | D |
| Buena Vista Lake Shrew *Sorex ornatus relictus* | CSC,FC | CV |

Continued on next page.

Table 17. Continued.

| **Mammals**, continued | **Status** | **Distribution by Region +** |
|---|---|---|
| Monterey Ornate Shrew *Sorex ornatus salarius* | CSC,FC | CC |
| Riparian Brush Rabbit *Sylvilagus bachmani riparius* | SC,FC | CV |
| Amargosa Pocket Gopher *Thomomys bottae amargosae* | CSC,FC | D |

ST,SE = State listed threatened, or endangered
CSC = California DFG Species of Special Concern
SC = State candidate
SpA = CNDDB Special Animal; declining and/or rare enough to warrent attention
FT,FE = Federally listed threatened, or endangered
FPE = Federally proposed endangered
FC = Federal candidate

Sources: Brode and Bury (1984), DFG (1992a), Laudenslayer et al.(1991), Miller et al. (1989), Remsen (1978), Stebbins (1966), Williams (1986), Williams and Kilburn (1984), Williams et al (1989), Zeiner et al (1988, 1990a, 1990b); CNDDB Special Animals List, December 1992; CNDDB list of Habitat Associations, 1/31/92

| **Fishes** | **Status** | **Distribution by Region +** |
|---|---|---|
| Green Sturgeon *Acipenser medirostris* | M&Y | NC,CV |
| Sacramento Perch *Archoplites interruptus* **EXTIRPATED** | CSC,FC | (CV,CC) |
| Owens Sucker *Catostomus fumeiventris* | CSC | ES |
| Modoc Sucker *Catostomus microps* | SE,FE | Mo |
| Mountain Sucker *Catostomus platyrhyncus* | CSC | ES |
| Santa Ana Sucker *Catostomus santaanae* | CSC,FC | SC |
| Klamath Largescale Sucker *Catostomus snyderi* | CSC,FC | NC |
| Shortnose Sucker *Chasmistes brevirostris* | SE,FE | NC |
| Rough Sculpin *Cottus asperrimus* | ST,FC | Mo |
| Bigeye Marbled Sculpin *Cottus klamanthensis macrops* | CSC | Mo |
| Desert Pupfish *Cyprinodon macularius* | SE,FE | D |
| Amargosa Pupfish *Cyprinodon nevadensis amargosae* | CSC | D |
| Owens Pupfish *Cyprinodon radiosus* | SE,FE | ES |
| Lost River Sucker *Deltistes luxatus* | SE,FE | NC |
| Tidewater Goby *Eucyclogobius newberryi* | CSC,FT | NC,CC,SC |
| Unarmored Threespine Stickleback *Gasterosteus aculeatus williamsoni* | SE,FE | SC |
| Santa Ana Threespine Stickleback *Gasterostous aculeatus santannae* | CSC,FC | SC |
| Mohave Tui Chub *Gila bicolor mohavensis* | SE,FE | D |
| Owens Tui Chub *Gila bicolor snyderi* | SE,FE | ES |
| Thicktail Chub *Gila crassicauda* | **EXTINCT** | (CV) |
| Bonytail *Gila elegans* | SE,FE | D |
| Arroyo Chub *Gila orcutti* | CSC | SC |
| Delta Smelt *Hypomesus transpacificus* | ST,FT | CV |
| Russian River Tule Perch *Hysterocarpus traski pomo* | CSC,FC | NC |
| River Lamprey *Lampetra ayresi* | CSC | NC,CV |
| Modoc Brook Lamprey *Lampetra folletti* | CSC | NC |
| Kern Brook Lamprey *Lampetra hubbsi* | CSC,FC | CV |
| Klamath River Lamprey *Lampetra similis* | CSC | NC |
| Pit Roach *Lavinia symmetricus mitulus* | CSC,FC | Mo |
| Navarro Roach *Lavinia symmetricus navarroensis* | CSC | NC |

Continued on next page.

Table 17. Continued.

| Fishes, continued | Status | Distribution by Region + |
|---|---|---|
| Gualala Roach *Lavinia symmetricus parvipinnis* | CSC,FC | NC |
| Monterey Roach *Lavinia symmetricus subditus* | CSC | CC |
| San Joaquin Roach *Lavinia symmetricus* ssp. | CSC | CV |
| Tomales Roach *Lavinia symmetricus* ssp. | CSC | NC |
| Hardhead *Mylopharadon conocephalus* | CSC | NC,CV,Mo |
| Coastal Cutthroat Trout *Oncorhynchus clarki clarki* | CSC | NC |
| Lahontan Cutthroat Trout *Oncorhynchus clarki henshawi* | FT | ES |
| Paiute Cutthroat Trout *Oncorhynchus clarki seleniris* | FT | ES |
| Pink Salmon *Oncorhynchus gorbuscha* | CSC | NC,CV,CC |
| Chum Salmon *Oncorhynchus keta* | M&Y | NC,(CV) |
| Coho Salmon *Oncorhynchus kisutch* | CSC | NC,CV,CC |
| Volcano Creek Golden Trout *Oncorhynchus mykiss aguabonita* | CSC,FC | CV |
| Summer Steelhead *Oncorhynchus mykiss gairdneri* | CSC | NC |
| Kern River Rainbow *Oncorhynchus mykiss gilberti* | CSC,FT | CV |
| Little Kern Golden Trout *Oncorhynchus mykiss whitei* | FT | CV |
| McCloud River Redband Trout *Oncorhynchus mykiss* ssp. | CSC,FC | Mo |
| Chinook Salmon, Spring Run *Oncorhynchus tshawytscha* | CSC | NC,CV |
| Chinook Salmon, Winter Run *Oncorhynchus tshawytscha* | SE,FT | CV |
| Sacramento Splittail *Pogonichthys macrolepidotus* | CSC,FC | CV |
| Colorado Squawfish *Ptychochelus lucius* **EXTIRPATED** | SE,FE | Mo |
| Amargosa Canyon Speckled Dace *Rhinichthys osculus* ssp. 1 | CSC,FC | D |
| Owens Speckled Dace *Rhinichthys osculus* ssp. 2 | CSC,FC | ES |
| Santa Ana Speckled Dace *Rhinichthys osculus* ssp. 3 | CSC,FC | SC |
| Longfin Smelt *Sprinchus thaleichthys* | M&Y | NC,CV |
| Bull Trout *Salvelinus confluentus* **EXTIRPATED** | SE,FC | (Mo) |
| Razorback Sucker *Xyrauchen texanus* | SE,FE | D |

**+ Regions** (see Map of Regions, Figure 69)
NC = North Coast/Klamath
CV = Central Valley
Mo = Modoc/Cascade
CC = Central Coast
ES = Eastside/Great Basin
SC = South Coast
D = Desert (Mainly represents Colorado River)

| | |
|---|---|
| ST,SE | = State listed threatened, or endangered |
| SC | = State candidate |
| CSC | = California DFG Species of Special Concern |
| FT,FE | = Federally listed threatened, or endangered |
| FPE | = Federally proposed endangered |
| FC | = Federal candidate |
| M&Y | = Moyle and Yoshiyama potential candidates for listing |

Sources: CNDDB Special Animals List, December 1992; CNDDB Listing Dates, January 1993 Moyle (1976), Moyle et al. (1989), Moyle and Yoshiyama (1992).

Table 18. California Salmonid Stocks Extinct or At Risk.

**Chinook Salmon**

***Winter Run***
R Sacramento River *
EX Calaveras River

***Spring Run***
R Smith River
R Klamath River
R Salmon River
R Trinity River
R South Fork Trinity River
R Sacramento River (incl. tribs.)
R Yuba River
EX San Joaquin River (incl. tribs.)
EX American River
EX McCloud River
EX Pit River

***Fall Run***
R Smith River
R Shasta River
R Scott River
R South Fork Trinity River
R Lower Klamath tributaries
R Redwood Creek
R Mad River
R Minor Humboldt tributaries
R Lower Eel River
R Bear River
R Mattole River
R Little River
R Russian River
R San Joaquin River
R Cosumnes River

**Coho Salmon**
R Smith River
R Klamath River
R Lower Klamath tributaries
R Trinity River
R Scott River
R Minor Humboldt tributaries
R Redwood Creek
R Wilson Creek
R Mad River
R Eel River
R Bear River
R Mattole River
R Ten Mile River
R Pudding Creek
R Noyo River
R Big River
R Little River
R Albion River
R Navarro River
R Garcia River
R Gualala River
R Russian River
R Small coastal streams
EX Malibu Creek

**Pink Salmon**
R Russian River
EX Klamath River
EX Sacramento River

**Chum Salmon**
EX Klamath River
EX Sacramento River

**Steelhead**

***Fall/Winter Run***
R Malibu Creek
R Santa Clara River
R Ventura River
R Santa Ynez River
R Little Sur River
R Big Sur River
R Carmel River
R Salinas River
R Pajaro River
R South San Francisco Bay tribs.
R Sacramento River
R Napa River
EX San Luis Rey River
EX San Mateo Creek
EX Santa Margarita River
EX Rincon Creek
EX Gaviota Creek
EX Maria Ygnacio River
EX Los Angeles River
EX San Gabriel River
EX Santa Ana River
EX San Diego River
EX Sweetwater River

***Spring/Summer Run***
R Smith River
R Klamath River
R Salmon River
R South and North Forks Trinity River
R Upper Trinity River
R New River
R Mad River
R Redwood Creek
R Middle and North Forks, Eel River
R Van Duzen River

**Sea-run Cutthroat trout**
R California coastal streams
R Lower Klamath River
R Mad River
R Wilson Creek
R Lower Eel River

R = Stocks at high or moderate risk of extinction, or of special concern
EX = Stocks known to be extinct

* = State listed endangered

Sources: Higgins (1992), Nehlsen et al. (1991).

# California Rivers: Restoration, Tools and Beginnings

5

*A Paul Bunyan saga tells how he floated many a log down the Round River . . . No one has suspected Paul of speaking in parables, yet in this instance he did. The [restless waters'] current is the stream of energy which flows out of the soil into plants, thence into animals, then back into the soil in a never ending circuit of life.*

*We of the genus* Homo *ride the logs that float down the Round River, and by a little judicious "burling" we have learned to guide their direction and speed. This feat entitles us to a specific appellation* sapiens. *The technique of burling is called economics, the remembering of old routes is called history, the selection of new ones is called statesmanship, the conversation about oncoming riffles and rapids is called politics. Some of the crew aspire to burl not only their own logs, but the whole flotilla as well. This collective bargaining with nature is called national planning.* Aldo Leopold, "The Round River" from *A Sand County Almanac*, 1949.

## Introduction

There are a great many public and private organizations that may have an interest in or some influence over a particular waterway. The sheer number of such organizations is often overwhelming. (See Table 19. Managing Entities for California's Wild and Scenic Rivers). Unfortunately, there is no one entity which synthesizes river and stream data, distributes it to all interested parties, arbitrates disputes between competing legitimate demands for the use of scarce river resources, and plans and coordinates watershed or bioregional level management. On any given waterway, those resources may include aggregates, fish and wildlife and their habitats, the consumptive use of water, recreation and aesthetics, flood control, hydroelectric power, water quality and many others.

Typically, each resource that may be provided by a river or stream has its own constituency, and each constituency is served by a specific single-purpose governmental body devoted to regulation

Table 19. Managing Entities for California's Wild and Scenic Rivers.

| | NPS | | | BLM | | | Indian Reservation | | | FS | | | Other Managing Entity | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| River | W | S | R | W | S | R | W | S | R | W | S | R | W | S | R | Total |
| Klamath | | | 1.0 | | | 1.5 | | | 29.0 | 12.0 | 21.0 | 177.5 | | 3.0 | 41.0 | 286.00 |
| Tuolumne | 37.0 | 17.0 | | 3.0 | | | | | | 7.0 | 6.0 | 13.0 | | | | 83.00 |
| Merced | 53.0 | 14.0 | 14.0 | 3.5 | | | | | | 15.0 | 2.0 | 12.5 | | | | 114.00 |
| Kings | 49.0 | | 6.5 | | | | | | | 16.3 | | 9.0 | | | | 80.80 |
| Kern | 27.0 | | | | | | | | | 96.1 | 20.9 | 7.0 | | | | 151.00 |
| Smith | | | | | | | | | | 78.0 | 30.5 | 187.85 | | .5 | 28.5 | 325.35 |
| Trinity | | | | | | 17.0 | | 6.0 | 8.0 | 42.0 | 22.0 | 71.0 | 2.0 | 11.0 | 24.0 | 203.00 |
| Eel | | | | 21.0 | 4.5 | 6.5 | 5.0 | 1.0 | 16.0 | 31.0 | | | 36.0 | 22.5 | 205.0 | 394.00 |
| Middle Fork American | | | | | | | | | | 32.9 | 9.7 | 35.0 | | | | 77.60 |
| South Fork American | | | | | | | | | | 26.3 | | | | | | 26.30 |
| North Fork American | 12.0 | | | | | | | | | | | | | | | 12.00 |
| Lower American | | | | | | | | | | | | | | | 23.0 | 23.00 |
| Total | 178.0 | 31.0 | 21.5 | 27.5 | 4.5 | 25.0 | 5.0 | 7.0 | 53.0 | 356.6 | 112.1 | 512.85 | 38.0 | 37.0 | 367.0 | 1776.05 |

W = Wild River Miles; S = Scenic River Miles; R = Recreational River Miles

NPS = National Parks Service; BLM = Bureau of Land Management; Indian Reservation = Hoopa Valley Reservation; FS = Forest Service.

Source: Bureau of Land Management, May 1992.

and/or advocacy of the development of rivers and streams for that particular constituency's needs. The net result of this narrowly focused regulatory and management activity is far too often the destruction of those natural values which made the river system valuable in the first place.

The development of economic analyses for proposed projects that will alter natural river systems in some way is another important subject related to the diversity of single-purpose entities involved in such projects. Economic analyses performed to justify single-purpose projects often ignore significant project costs which are more difficult to estimate than the capital outlay costs for the proposed project. A clear picture of damage to ecosystems and particular resources might often make an otherwise attractive project economically infeasible. It is therefore not necessarily in the best interest of the project proponent to evaluate *all* of a project's potential costs. Even though the task of estimating the economic value of resource damage is difficult, the cost of making alternative uses, especially extractive uses, of public trust lands should reflect the real economic and environmental cost of pursuing those uses, so that fully informed and balanced decisions are possible.

As demonstrated elsewhere in this report, when rivers and streams are "loved" for one single purpose, they are often "loved to death" for all competing purposes. There is a powerful need to develop mechanisms to harmonize competing uses where possible, and to decide between uses when harmony is not possible. That is the essential responsibility of the state as public trustee.